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POOR PRECIPITATION FORECASTS FROM THE LIMITED AREA MODEL

by
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22 September 1993

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Report and recommendations - 22 September 1993

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1. SUMMARY

1.1 Scope

A major use of the limited area model is to provide forecast guidance on precipitation. The T+24 and T+36 forecasts from 00UTC and 12UTC are key products and are routinely verified by CFO. Since the introduction of the unified model in June 1991 the subjective assessment has highlighted a tendency to poorer performance in summer months with the proportion of C (serious errors) marks rising from ~20% to ~30% at T+24 and from ~25% to 35% at T+36. This was particularly apparent for May, June,August and September 1992.

Following the poor performance of the LAM in 1992 a study was undertaken to see what more could be learnt about the causes *given the current assessment and verification procedures*. All forecasts given a C mark by CFO for the period May to September 1992 were surveyed and an attempt made to classify them according to the major deficiencies and identify common characteristics (section 2, example cases are described in Appendices A to F) . Standard objective verification was also examined to see if any clues to the causes were apparent (section 3); also to see whether the subjective assessment was confirmed and if any impact from model changes made since could be discerned. The conclusions of these studies are given in section 4.

In doing this study some difficulties were encountered as set out below. Recognizing that time is limited for both forecasters and modellers some recommendations of how the classification and verification may be improved have been proposed. The aim is to provide a means to filter out the important messages and results more effectively without overburdening everyone with extra tasks.

1.2 Difficulties

The main difficulties were:

1) Searching through CFO comments and examining 160 forecasts is very time consuming. The assessment comments vary widely and are often not detailed enough to quickly identify the reason for the poor mark. The system is paper based and not easily accessible.

2) There is little information to help identify the systematic behaviour of the model beyond the simple separation into C1(Rain fell, nil forecast) and C2(rain forecast, nil observed). The current assessment procedure is very limited so that even a simple investigation to check the quality of the analysis is rarely included.

3) Assessing whether a change such as the modification to include convective downdraughts (made in April 1993) has actually improved the forecasting of showers (as indicated by pre-operational tests) is impossible beyond very subjective comments relying on forecasters' memories. The historical record of objective verification cannot discriminate between showers and dynamic precipitation.

4) Forecasting research staff do not have the time to assess in detail the daily performance of the operational models and nor should they do so since the forecasters using the model are far better placed to make such judgements. An effective means of analysing these, identifying common *systematic* errors and areas for investigation is however required. Given a suitable observational database (see recommendation 3 below) FR could set up an *objective* assessment procedure.

5) On-line access to radar data is not yet available to the modelling groups in FR.

6) Monthly mean statistics from standard objective verification are of little help in identifying causes of error. They do reveal some systematic model problems.

1.3 Recommendations:

1) A machineable database of forecasters' assessments should be initiated. This should be more extensive and be designed to allow information to be easily keyed in and extracted. Reasons for serious errors could be entered by selection from a pre-set list of main categories. The database could provide an "objective" means to quantify aspects of model performance noted by forecasters such as the treatment of trough disruption, overdevelopment in moist tropical airstreams etc.

2) Cases where there were problems with the analysis need to be identified as part of the assessment procedure. Ideally these should be excluded in tests of purely model changes eg revision of evaporation of precipitation. Conversely cases with specific problems in analysing humidity etc. could be used in tests of new analysis methods.

3) To properly judge how well weather is forecast by the limited area and mesoscale models there needs to be a regional verification of precipitation (including snow/rain distinction), cloud and visibility. At present there is very little systematic comparison between the LAM and MES models to evaluate whether the extra detail provided by the MES is realistic. The surface observations need to be supplemented by radar and satellite information. A scheme such as that proposed a few years ago by T. Davies where the main weather elements for each regions were coded every three hours into a database by the Frontiers forecaster could be considered. Similar regional products from the models could be easily made available and compared.

4) FR modelling groups to have on-line access to radar and assessment databases.

5) Time series of standard verification should be used to identify periods of particularly low (or high) performance.

2 POOR SUMMER RAINFALL FORECASTS FROM THE LIMITED AREA MODEL (MAY - SEPTEMBER 1992)

INTRODUCTION

Rainfall forecasts from the limited area forecast are assessed in the C.F.O. at T+24 and T+36 and awarded a score of "A","B" or "C", according to the key below;

"A"	Excellent guidance
"B"	Still good guidance but some errors of detail
"C1"	Rain fell - nil forecast
"C2"	Nil fell - rain forecast

A poor summer rainfall forecast was defined as one receiving a "C" score at T+24 and/or T+36 during the period May to September 1992 inclusive. C.F.O. forecasters' assessment of the rainfall forecasts for the period May to September 1992 identified 184 of these forecasts (30%) . The C.F.O. assessment is summarised in Tables 1a and 1b below.

	T+24			
	A	B	C	
May	21	22	19	
June	22	25	13	
July	21	28	11	(2 missing)
August	17	26	19	
September	11	29	20	
Totals	92	130	82	

TABLE 1a. C.F.O. assessment of limited area model rainfall forecasts for the U.K. verifying at T+24 for the period May to September 1992

	T+36			
	A	B	C	
May	19	25	18	
June	18	24	18	
July	16	29	15	(2 missing)
August	13	24	25	
September	6	28	26	
Totals	72	130	102	

Table 1b. C.F.O. assessment of the limited area model rainfall forecasts for the U.K. verifying at T+36 for the period May to September 1992

In order to add extra detail to the brief C.F.O. assessment, all rainfall forecasts assessed as "C" were examined to determine the likely causes of errors. Since there were 184 of these forecasts altogether, no attempt could be made to do detailed case studies of every one. These 184 forecasts were reduced to 160 since 24 forecasts were assessed as

"C" at both T+24 and T+36 for exactly the same reason. The main categories of error are shown in Table 2 below.

T+24/T+36 "C" assessments

160

Rainfall deficient		Distribution errors	Rainfall excessive	
73		49	38	
A	C	E	B	D
Convective	Dynamic		Convective	Dynamic
36	37		17	21
23%	23%	31%	10%	13%

Table 2 Main categories of error in Limited Area rainfall forecasts at T+24 and T+36 during the period May to September 1992.

CATEGORY A. - SHOWERS MISSED OR UNDERESTIMATED 23%

Nearly a quarter of the rainfall forecasts given a "C" assessment score last summer were criticised for being deficient in showers. A review of poor shower forecasts from last summer showed a number of shortcomings of the convection scheme. The main model problems are listed below.

(a) The operational version of the limited area model used last summer (henceforth called op-old) was poor at predicting light or moderate showers overland, especially in polar airmasses.

(b) In these cooler airmasses, the model often forecast convective cloud, depth 10,000 feet to 14,000 feet, with freezing level 3000 feet to 5000 feet, without predicting any rain. This could be due to the convective cloud just failing to fulfill the critical values of cloud depth and cloud top temperature required for showers overland (i.e 4000m depth (13,000feet) or cloud top temperature <-10C) or due to the rain evaporating before reaching the surface.

(c) The model airmass was often too dry or stabilised too quickly.

(d) The model's diurnal cycle was too early with showers developing too early and dying away too soon, often by 18Z.

(e) The model often underestimated the extent of showers over the U.K.near the centre of a cold pool.

The current version of the limited area model , with effect from 27/04/93, (henceforth to be called op-new) , uses a modified convective scheme containing the

convective downdraught and rapidly mixing boundary layer schemes. The evaporation of convective rain has been made intensity dependent and less severe than the old scheme which assumed a rainfall intensity more typical of the tropics. The limited area trial (described in Working Paper No 149[1]) to test the impact of these changes suggested that the new convection scheme will be more successful at predicting light or moderate showers in cooler airmasses. It should also improve the diurnal cycle problem by predicting more showers at 18Z.

Some widespread thundery outbreaks develop as a cold pool or short wave upper trough crosses the U.K.. Small errors in the forecast position and curvature of the upper trough or cold pool can result in poor shower forecasts. Even when the upper low is accurately forecast, the model often fails to predict the extent of showers near the centre of the cold pool.

Three examples of cases in this category are described in Appendix A at the end. Two of the examples (DT 12Z 01/05/92 and DT 00Z 10/08/92) compare shower forecasts from the old and new convection schemes, whilst the third case (DT 12Z 17/09/93) gives an example of showers associated with a cold pool over the U.K.

CATEGORY B - SHOWERS OVER-ESTIMATED 10%

Approximately 10% of the rainfall forecasts given a "C" assessment score last summer were due to the model over-predicting showers. The common characteristics of these cases were;

(a) warm, moist potentially unstable airmasses;

(b) high 850mb wet bulb potential temperatures (> 14C);

(c) the model's diurnal cycle was 3-4 hours too early so that forecast showers were often too widespread at 12Z.

The new convection scheme, including convective downdraughts and the rapidly mixing boundary layer scheme, is not expected to correct the over-prediction of showers in warm, moist airmasses. The limited area model often predicts correctly the development and organisation of heavy showers and thunderstorms in the warm, moist air ahead of a cold front[3] but the timing is often too fast and the predicted heavy showers too widespread. The model cannot be expected to predict the often very localised nature of severe thunderstorms.

When forecasts from the two convection schemes were compared daily during the summer of 1992, the new scheme forecast more showers on 90% of occasions.

Two examples of forecasts which over-predicted showers over the U.K. (DT 12Z 30/05/92 and DT00Z 08/06/92) are described in Appendix B at the end.

CATEGORY C - . DEFICIENT IN DYNAMIC RAIN 23%

About a quarter of the poor rainfall forecasts from last summer were due to the limited area model under-estimating rainfall amounts over the U.K. Many of these cases were associated with a cold pool or upper trough over Biscay or Northern France. Some common characteristics noted with these cases are listed below.

(a) Upper trough position seemed to be correct but weak forcing ahead of the trough resulted in the development of the rain area being missed or retarded.

(b) Errors in the flow ahead of the upper trough, resulting in weak thermal advection.

(c) Humidity analysis deficient, especially at low levels, leading to too little rainfall in the forecast.

(d) Rainfall associated with weak fronts died out too soon, probably due to the evaporation of any rain before reaching the surface, also due to weak vertical motion.

(e) Failure to represent frontal waves;

(f) Major development errors;

(g) Small scale features (e.g. short wave troughs) not represented.

Two examples of limited area cases which under-predicted the rainfall over the U.K.; DT 00Z 14/08/92 (weak warm front over Scotland) and DT 12Z 24/06/92 (slow moving cold front) are described in Appendix C at the end.

In addition, great effort has been put into explaining the causes behind the poor limited area model forecast of the heavy rain and floods on 22nd/23rd September 1992. This case is not discussed in this note but it has been described in detail in Technical Note No. 59[2].

Transplant experiments carried out on the two key forecasts, DT 00Z 22/09/92 (poor forecast) and DT 12Z 22/09/92 (good forecast) show that the upper level forcing may be well forecast but errors in the low level anomaly (850mb wet-bulb potential temperature) can lead to late development and position errors. The model physics is able to produce reasonably large rainfall totals provided the upper and lower level anomalies are favourably positioned. A similar result has been found for 1st April 1993.

CATEGORY D - EXCESSIVE DYNAMIC RAINFALL FORECAST 13%

About 13% of the poor rainfall forecasts from last summer were due to the model predicting excessive rainfall over or near the U.K.. Some common characteristics of these cases are listed below.

a) Differences between global and limited area forecasts verifying at the same time suggest that model resolution may be important.

(b) Excessive rainfall was often accompanied by strong warm advection , high vertical velocity, high wetbulb potential temperatures(> 14C).

(c) Strong forcing ahead of an upper trough over Biscay often resulted in either the development of a spurious rain area or a rain area developed well in advance of reality.

(d) Over development of a baroclinic wave.

(e) Over active fronts.

(f) Moisture analysis and advection problems.

(g) Analysis errors in the Atlantic.

(h) Excessive light rain or drizzle predicted from cloud in the lowest 1-3 layers.

Four examples of poor rainfall cases from this category are described below. Two cases describe the over-development of baroclinic waves (DT 00Z 07/08/92, DT 00Z 19/08/92), one resulted from a poor analysis in the Atlantic (DT 12Z 25/07/92) and one deals with the problem of excessive rain/drizzle from boundary layer cloud (DT 12Z 29/09/92).

CATEGORY E. - RAINFALL DISTRIBUTION ERRORS (31%)

Approximately 31% of the poor rainfall forecasts during last summer were due to distribution or development errors. Some common characteristics of these cases are listed below.

(a) Rainfall intensities correct but timing errors 3-6 hours (2:1 fast:slow)

(b) Errors in timing of frontal waves.

(c) Atlantic analysis errors (surface, upper air and moisture)

(d) Bad evolution errors

(e) Inconsistency between successive forecasts

This category covers a wide range of forecast problems, ranging from simple timing errors to large evolution errors. An example of a simple timing error is given by the forecast from DT 12Z 14/08/92, described in Appendix E. Generally timing errors are easy for the forecasters to spot and correct.

A common complaint from C.F.O. forecasters concerns the inconsistency of the advice received from successive forecast runs. We expect the accuracy of the forecast to improve as the rainfall event approaches, but the T+24 forecast is not always better than the T+36 and even the T+12 forecast can be seriously in error. We have examined one

sequence of forecasts (DT 00Z 23/8/92, DT 12Z 23/08/92, DT 00Z 24/08/92), in which the T+36 forecast was better than both the T+12 and T+24 forecasts. The errors in all three of these forecasts can be attributed to deficiencies in the analysis over the Atlantic.

3 STANDARD VERIFICATION

Hit scores (rain-yes/no) for limited area rainfall forecasts over the U.K. for the six hour period verifying at T+24/T+36 are listed in Table 3 below for the period May 1992 - Aug 1993 inclusive. In general,the standard verification figures do not help much in deciding the causes of poor rainfall forecasts over the U.K.. However, they do point to a few systematic errors.

Month	T+24		T+36	
	DT00Z	DT12Z	DT00Z	DT12Z
May 92	81.7%	75.9%	74.9%	80.9%
June 92	84.9%	81.9%	77.3%	82.8%
July 92	78.5%	73.5%	70.2%	75.1%
Aug 92	73.4%	73.3%	69.0%	73.4%
Sep 92	68.1%	68.9%	63.8%	66.3%
Oct 92	73.3%	73.7%	70.5%	70.1%
Nov 92	72.4%	72.9%	71.2%	70.2%
Dec 92	72.0%	73.6%	63.2%	63.2%
Jan 93	not available		not available	
Feb 93	65.9%	64.5%	63.1%	64.0%
Mar 93	76.2%	73.9%	66.3%	74.6%
Apr 93	74.1%	72.5%	66.1%	73.0%
May 93	79.2%	76.3%	70.2%	73.3%
June 93	79.3%	73.1%	74.8%	73.4%
July 93	73.8%	67.9%	62.1%	71.1%
Aug 93	77.4%	78.8%	75.3%	70.2%

TABLE 3. Hit rate (rain yes/no) of LAM rainfall forecasts over the U.K. for six-hour periods verifying at T+24/T+36

August and September 1992 were very wet (it was the wettest August over England and Wales since 1956) and the hit rate (rain yes/no) for the U.K. dipped below 70% (Figs V1,V2). September was the worst month overall apart from February 1993 which was very dry with a hit rate of ~64%). Forecasts verifying at 00Z were better than forecasts verifying at 12Z in most months (Fig V3) but the reasons are not clear from these figures alone.

The bias (ratio % occurrences rain forecast: % occurrences rain observed) is no worse for summer months than other months but does have a diurnal variation which suggests that convective activity may sometimes be too strong (Figs V4-V7, NB "winter" half-year months have symbols). Over the sixteen months listed in Table 3, the average bias at T+06 was 0.9 increasing to 1.5 by T+36, which also points to a rainfall spin-up problem in the model.(However, note this is not a true bias of rainfall amount cf Figs V14,V15; the model could have a tendecy to underforecast rainfall amounts generally but

produce small amounts of rain nearly everywhere which would give a large value to this measure of bias.) The summer months meaned together generally have a lower bias than the meaned winter months (Figs V8,V9). This measure seems to conflict with the subjective assessment. The evidence for a positive impact from the change to ∇^4 diffusion of humidity in the global model (implemented 9 March 1993) is rather inconclusive since although the bias for May-Aug 93 is generally lower than the winter period it is greater than for the May-Sep 92 period .

There is a steady increase in the light rain forecast/nil observed through the forecast which shows that the drizzle from low cloud increases with forecast time (Figs V10-V13). The average percentage light rain forecast/nil observed at T+06 was 7.6 increasing to 20.6 (DT00Z), 16.6 (DT12Z) at T+36. Forecasts verifying at 12Z were worse in this respect, pointing to a problem of persistent low cloud/drizzle during the period 06Z-12Z.

The bias in rainfall amounts for September 92 shows the model to generally underestimate total precipitation (Fig V14) when compared to the MORECS estimates (Fig V15) with less than half the observed totals in many places and particularly for southern and eastern areas. It should be remembered that the exceptional event of 22/23 contributed significantly to the totals.

4 CONCLUSIONS

1. Summer rainfall forecasts are thought to be less accurate than winter rainfall forecasts due to weaker dynamic forcing and the increased importance of convection. (Monthly statistics do not seem to support the subjective impression?)

2. Generally the worst cases had large analysis errors. Biggest error is in the moisture analysis (model has no cloud analysis and humidity data are sparse in the Atlantic). The inconsistency between successive forecast runs may be attributed to analysis problems in the Atlantic on many occasions. See appendix F for a recent case for July 93 where the mispositioning of a front is clearly related to over strong low level winds which raises questions of data coverage in the Atlantic.

3. There may be large errors in rainfall even though the errors in upper forcing are relatively small. The moisture/temperature of the low level often play a decisive role. Several poor forecasts had too high/low 850mb wet bulb potential temperatures.

4. The revised convection scheme including downdraughts has improved convective cases particularly the cooler airmass ones. The evaporation of convective rain is now intensity dependent and less severe than previously which assumed a rainfall intensity more typical of the tropics.

5. The revised convection scheme does not correct the over prediction of showers in warm,humid airmasses, partly because the model is often too moist and partly because the model may be convecting on the grid-scale.

6. Resolution

a) Horizontal - some cases overdevelopment in the limited area model forecast compared to global forecasts, although generally the precipitation is better defined in the limited area forecast. The main factor of the over-development was found to be model resolution rather than model physics.

b) Vertical - in a few cases better low cloud and reduction in drizzle was achieved with higher resolution in the boundary layer.

7. Comparison of poor and good forecasts (with transplant experiments) can help to understand dynamical developments and causes of differences.

8. The standard verification scheme does indicate a few systematic errors. In general it cannot help much in identifying the causes of errors and it does not appear to discriminate summer and winter behaviour strongly , although perhaps a more extensive investigation than attempted here might reveal better results.

This study has considered the major causes of poor rainfall forecasts in the summer of 1992. The division of the cases into different categories is subjective and has had to be simplified . The two major impressions emerging from this work are given by items 2 and 3 of the conclusions above;

a) the model needs a better analysis over the Atlantic, especially of humidity;

b) the coupling between the upper and low level anomalies is important.

REFERENCES

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2. Forecasting Research Technical Note No.59. August 1993
"The 1992 Autumn Equinoctial Downpour; Causes and N.W.P. Model Assessment."
(J.R.Grant, M.J.Bader, C.A.Wilson, T.Davies, S.P.Ballard)

3. Weather - July 1993 .
"Severe Thunderstorms over southeast England, 20/21 July 1992: Satellite and Radar Perspective of a Mesoscale Convective System." (E.McCallum and A.J.Waters).

APPENDIX A.- SHOWERS MISSED OR UNDERESTIMATED

1. DT 12Z 01/05/92

The radar images in Figures 1a and 1b show the distribution of showers at 12Z and 18Z in the cool northwesterly airstream covering the U.K.on 2nd May. At 12Z, the heaviest showers were observed over Lincolnshire and South Yorkshire with scattered light showers starting to develop elsewhere. The operational (op-old) rainfall forecast for T+24, shown in Figure 2a, predicted isolated light showers over Lincolnshire and East Anglia but under-estimated the extent of the showers elsewhere. The rainfall forecast for T+24 from the new version of the LAM (op-new), shown in Figure 2b, predicted a much wider and improved coverage of showers.

At 18Z, the radar picture, Figure 1b, shows that showers were still widespread over Central England. However, the operational (op-old) T+30 rainfall forecast for this time, shown in Figure 2c, failed to predict any showers at all. The new version (op-new) did predict some showers for 18Z in the southeast (see Figure 2d).

2. DT 00Z 10/08/92

An unstable westerly airstream covered the U.K. on 10th August with showery troughs crossing England and Wales. The distribution of showers at 12Z and 18Z on 10th August is shown in the radar images in Figures 3a and 3b. The radar shows a trough over Wales and Southwest England at 12Z moving northeastwards to lie from Manchester to Nottingham to Colchester by 18Z. The op-old and op-new forecasts for T+12 and T+18, verifying at these times, are compared in Figures 4a - d.

The operational (op-old) forecast (Figures 4a and 4c) failed to predict any showers at T+12 and T+18 even though there was a showery trough crossing the country at this time. At T+18 it did predict some convective cloud, depth 10,000-14,000 feet but no rain.

The new version of the LAM forecast (op-new) (Figures 4b and 4d) predicted the position and movement of the showery trough well. At T+12, it predicted some light

showers over Wales and Southwest England approximately in the position of the trough. At T+18, the op-new shower forecast (Figure 4d) was again much better, predicting showers over Northwest England, the East Midlands, East Anglia and Southeast England from convective cloud depth 15,000-19,000 feet. Showers over Scotland at 18Z were also predicted by the op-new forecast but not by the op-old forecast..

3. DT 12Z 17/09/92

Figure 5 shows the movement of a small cold pool across Southern England and the English Channel during the 18th September. The weather over England and Wales associated with the cold pool was mainly cloudy with outbreaks of rain or showers, some thundery. The heaviest rainfall during the day was reported from Upton Scudmore on the Salisbury Plain.

The surface analysis and rainfall distribution for 12Z 18th September are shown in Figure 6. The heaviest rainfall at 12Z was observed over Northeast England, associated with the cold front, and also over Avon and the Salisbury Plain, associated with thunderstorms.

The model's forecast position of the cold pool at T+24 (Figure 7) was accurate to within one grid-point but there was a small error in the intensity of the upper low. Inspite of the accuracy of the cold pool position, the forecast rainfall for T+24 (Figure 8) was poor. The centre of low pressure was predicted too far north and the forecast distribution was poor and the showers too light. The model's forecast convection was confined to the northeast of the cold pool, associated with the cold front. No convective cloud was forecast near the centre of the cold pool, so the band of thundery rain over Avon and the Salisbury Plain was missed by the model.

APPENDIX B - SHOWERS OVER-ESTIMATED

4. DT 12Z 30/5/92

Figures 9a and 9b show the distribution of showers at 12Z and 18z 31st May . At 12Z, showers were only just beginning to develop over England but by 18Z the showers were widespread especially over North London, the Midlands, the Pennines and Western Scotland. Very heavy rain was reported over parts of Hertfordshire, Buckinghamshire and Northamptonshire associated with a slow moving thunderstorm (73mm in 130 mins at one place).

The old operational (op-old) rainfall forecasts for T+24 and T+30, verifying at 12Z and 18Z 31st May are shown in Figures 10a and 10c respectively. The maximum convective activity was forecast at 12Z, with the model predicting widespread showers much too soon. By 18z, the model's convection was already dying down, and, although the forecast distribution was good, the intensity was too light.

The new operational (op-new) rainfall forecasts for T+24 and T+30 are shown in Figure 10b and 10d. Again, the diurnal cycle is too early with maximum showers predicted at 12Z. The forecast showers are also too widespread, although some decrease in the number of heavy showers predicted over Scotland and Europe is an improvement.

5. DT 00Z 08/06/92

The analysis for 12Z 9th June (Figure 11a) shows a slow moving depression centred over Brest and a slack, warm, thundery airmass over the U.K.. Thunderstorms developed over the Manchester and Glasgow areas by midday, becoming more widespread during the late afternoon. The distribution of showers / thunderstorms at 12Z and 18Z is shown by the significant weather charts in Figure 11b and confirmed by the radar images in Figures 12b and 12c respectively. Particularly heavy rain was reported over London (70.2mm in Lewisham including 25mm in one hour) and also over Manchester.

The operational (op-old) rainfall forecast for T+36 (Figure 12a) verifying at 12Z 9th June predicted widespread heavy showers over much of Wales, Western and Central England, which was overdone for 12Z but better guidance for late afternoon.

APPENDIX C - DEFICIENT IN DYNAMIC RAIN

6. DT 00Z 14/08/92

On the 14th August, a ridge of high pressure covered the U.K.giving most areas a fine day. However, by midnight, a weak warm front was approaching Western Scotland with the cloud becoming thick enough to give light rain and drizzle. The distribution of rain over Scotland is shown by the radar image in Figure 13c.

The T+24 forecast from the operational limited area model forecast (Figures 13a, 13b) predicted medium cloud but no rain over Scotland. The T+24 model profile for Stornaway is compared with the radio-sonde ascent in Figure 14. The model ascent is too dry, being saturated for only one model layer at 700mb and any rain from this layer would evaporate before reaching the surface. The radio-sonde ascent for Stornaway was moister over a greater depth between 900 and 600mb. This case was an example of a weak front moving into a ridge of high pressure with the model lacking in moisture and vertical ascent.

7. DT12Z 24/06/92

During the 24th June, Scotland and Northern Ireland remained generally cloudy with rain at times due to a slow moving cold front. Further south, high pressure dominated with England and Wales having a fine day.

The LAM forecast for T+24 predicted little, if any, rain on the front at 12Z on the 25th. The model ascents predicted low cloud only for the ascents over Scotland. The poor forecast was due to lack of moisture, weak thermal gradient and no vertical ascent.

APPENDIX D.- DYNAMIC RAIN EXCESSIVE

8. DT 00Z 07/08/92

An upper trough was moving eastwards into Biscay and Spain, with the southwesterly winds over Biscay gradually backing and increasing, bringing a moist unstable airmass northwards towards the U.K. These conditions were favourable for the development of a thundery low over Northern Spain, which later moved northwards to cross Southern England during the early hours of August 9th. Associated with this

depression was a band of severe thunderstorms.

The limited area model forecast from DT00Z 07/08/92, shown in Figure 15, developed quite a vigorous low of 1002mb over South Wales at T+36, verifying at 12Z 08/08/92. In reality , as the analysis for this time shows in Figure 16a, there was still an easterly flow over Southern England and Wales, with a less developed low of 1009mb over Northern France. There were no obvious errors in the analysis and the handling of the upper trough in the forecast was correct. Basically, the model evolution was correct but the timing was too fast by about 12 hours and the development too vigorous.

Comparing the T+48 LAM forecast , Figure 17a, with the verifying analysis, Figure 16b, we see that the model overdeepened the low by 9mb, the thermal gradient on the eastern side was too strong and the low advected much too far north. The global T+48 forecast from DT00Z 07/08/92 , shown in Figure 17b, was better than the LAM forecast with no over-deepening of the thundery low.

The critical time in the LAM forecast (Figure 15) was between T+24 and T+36, with the development of a large area of dynamic rain over Biscay and rapidly increasing vertical velocity. Figure 18 shows the high vertical velocity (204 mb/hr at 700mb)predicted at T+36, with the warm moist tropical air (850mb wetbulb potential temperature 20C in the centre of the low) and strong low level winds (64 knots at 850mb,75 knots at 700mb) on the eastern flank of the low) associated with the deepening low.

The model output suggested that the over-deepening was connected with instability, large vertical velocities and the release of large quantities of latent heat. Several reruns of this case were carried out to try to determine the critical factors in the development of the vigorous low.

(a) Impact of data assimilation and boundary forcing

The LAM forecast rerun from DT12Z 06/08/92 for 60 hours with no assimilation of data is shown in Figure 19. The low was still advected too quickly northwards, this time into the North Sea instead of Scotland, but with less overdeepening of the low.
Conclusion - advection errors in the forecast of the low could be partly attributed to boundary forcing.

(b) Impact of limited area model data assimilation

The LAM forecast rerun from the global analysis DT 00Z 07/08/92 for 48 hours was very similar to the forecast run from the limited area model analysis. The low was still too deep and too far north (see Figure 20a).
Conclusion - data assimilation had only a very small impact on the evolution of the low.

(c) Impact of the physics (i.e latent heat and convection)

The LAM forecast was rerun from 00Z 07/08/92 for 48 hours with the physics routines switched off except in the boundary layer. The T+48 forecast is shown in Figure 20b. The depression was less deep than in the operational forecast but still 5mb deeper than the actual low and further south.
Conclusion - the model physics had a small impact on the deepening of the low but not in the advection errors.

(d) Impact of model resolution

The LAM forecast rerun from DT 00Z 07/08/92 for 48 hours at global resolution (shown in Figure 21) did not over-deepen the low. This was the best forecast from the limited area model.

Conclusion - Running the limited area model at global resolution corrected the forecast deepening and advection errors.

9. DT 00Z 19/08/92

A small thundery low forming over Northern Spain at 00Z 19/08/92 moved slowly northwards during the next 24 hours, without deepening, to reach the Brest peninsular. Subsequently, the low deepened slightly by 4mb and moved northeastwards into Holland. The evolution of the depression is shown in the analyses at DT12Z 20/08/92 and DT00Z 21/08/92 shown in Figures 22 (a) and (b) respectively..

The limited area model forecast from DT12Z 18/09/92 and DT00Z 19/08/92 developed a low 12 hours early, over-deepened it by 10-15mb and moved it too far north, and hence provided poor guidance on rainfall distribution and amount over the U.K. Comparing the T+48 forecast from DT00Z 19/08/92 (Figure 23) with the verifying analysis (Figure 22b), the model depression is 13mb too deep and too far north. The T+48 global forecast from DT00Z 19/08/92 was more accurate than the LAM forecast. This case is very similar to the previous case, DT00Z 07/08/92. Again, the over-deepening in the LAM forecast appeared to be connected with model resolution and instability. The T+36 forecast, Figure 24, shows the large vertical velocities, strong thermal advection and high wet bulb potential temperatures associated with the developing low.

10. DT 12Z 25/07/92

The significant features in the Atlantic at analysis time were a confluent upper trough in the Atlantic and a strong westerly jet (maximum speed 160 knots) at 50N. The CFO analysis for 12Z 25/07/92 (Figure 25(a)) shows 2 distinct wave depressions in the Atlantic. The position of the first at 47N 31W is confirmed by ship observations and satellite pictures. This wave moved quickly eastwards in the strong flow without deepening to cross England between 12Z and 18Z on the 26th with a further wave developing to the southwest. The second wave centred at 41N 47W was centred well south of the strong flow and moved slowly eastwards during the next 24 hours without deepening. The analysis 36 hours later at 00Z 27/07/92 (Figure 25(b)) shows a cold front over southeast England with a wave just clearing East Anglia and a westerly flow over the rest of the U.K..

This complex detail in the Atlantic was not well analysed by the LAM. The dominant feature in the LAM analysis (Figure 26 (a),(b)) was a small, intense low centred at 44N 35W associated with very large vertical velocities of -80mb /hour, strong warm advection and high wetbulb potential temperatures of 18-20C. This low was present in the background and due to lack of data , it's position was uncorrected in the assimilation cycle. As a result, the low came under the infuence of the strong flow over the Atlantic and was forecast to move northeastwards to cross the U.K. by T+36 as a spurious deep wave.(see Figure 27).

CFO tried to improve the analysis by inserting many bogus pressure and upper air observations (total 97!). However, the bogussing was unsuccessful because the model analysis had such an intense low in the wrong position.

11 DT12Z 29/09/92

Over England and Wales, the evening of 30th September was fine with clear periods but fog patches formed inland later in the night. A common model problem is that of forecasting small amounts of rain when none is observed. The operational T+36 forecast verifying at 00Z 1st October earned a "C" assessment for predicting small amounts of light rain from low cloud in the west and south instead of clear skies. The rainfall and low cloud forecasts are shown in Figures 28(a) and (c) respectively. The light rain over southwest and southern England is coming from low cloud in the bottom two layers of the model as indicated by the model tephigrams for Aughton and Camborne shown in Figures 29(a) and (b).

The LAM forecast was rerun with higher vertical resolution, using the same 30 levels as in the mesoscale model, including 13 layers instead of 5 in the boundary layer. The impact of the increased vertical resolution on the rainfall and low cloud forecasts can be seen in Figures 28 (b) and (d) respectively. The spurious light rain has been removed and amounts of low cloud over most of England reduced. The increased resolution tephigram forecast for Camborne (Figure 29c) is drier than the operational with a better structure in the boundary layer.

APPENDIX E. - RAINFALL DISTRIBUTION ERRORS

12. DT 12Z 14/08/92

This case gives an examplele of a rainfall forecast given a "C" assessment due to a simple timing error. The radar image for 12Z 15th August, (Figure 30(a)), shows a frontal rain band lying from Eastern Scotland southeastwards down the Irish Sea. The model's forecast position for the front at T+24, shown in Figure 30(b), lies over Central Ireland. The forecast rainfall intensities are good but the timing of the front is about 3-4 hours too slow. This is due to the model forecasting too strong a ridge over Southeast England.

13-15. DT 00Z 23/08/92 DT 12Z 23/08/92 DT 00Z 24/08/92

The analysis for 12Z 24/08/92, Figure 31(a), shows a cold front in the southwest approaches with a moist southwesterly airstream over Biscay. The radar image for 12Z , Figure 31(b), shows an area of mainly light rain associated with a wave on the cold front just moving into Southwest England.

In order to predict the formation and movement of a frontal wave, the model needs an accurate analysis of temperature, moisture and winds in the baroclinic zone. In this case, however, very little data is available to help the analysis in the Atlantic.

This example highlights the difficulty the model has in predicting frontal waves with any accuracy. It compares three successive model forecasts of the position of the wave at 12Z and shows the occasional inconsistency between successive model runs. The T+12, T+24 and T+36 forecasts all verifying at 12Z 24th August are compared in Figures 32(a),(b),(c) respectively. In this case, the longest forecast verifying at T+36 was the best forecast for the wave over Southwest England. Given a reasonably good forecast at T+36 we might have expected that the T+24 and T+12 forecasts would be equally good. In fact both were poor, producing a spurious area of rain well to the north of southwest England. The T+24 forecast provoked the comment "pathetic" from the CFO assessor!

The model's analyses for mean sea level pressure, wet bulb potential temperature, cloud, thermal advection and vertical velocity for 12Z 23/08/92 are shown in Figures 33 (a),(b),(c). A significant feature is a small low pressure centre (1005mb) at 47N 27W, associated with a strong thermal gradient on the northern side and fairly high wet bulb potential temperatures of 14-16 degrees. There is also an area of medium and low cloud just to the north of the centre associated with warm advection and vertical velocity. In the subsequent forecast, this centre moved northeastwards producing the area of spurious rain over Ireland at T+24 (Figure 32(b)..

A copy of the CFO surface analysis in the eastern Atlantic is shown in Figure 34. A new centre has been analysed at 47N 32W, five degrees further west than the centre analysed by the model. The meteosat visible and infra red satellite images for 12Z are shown in Figures 35 (a) and (b) respectively. A comparison with the model cloud analysis indicates that the model's cloud analysis is incorrect, with an area of spurious cloud at 20-25W.

These comparisons indicate that the poor forecast at T+24 is probably due to errors in the analysis in the Atlantic. The same is true for the poor T+12 forecast.

APPENDIX F -FRONTAL POSITION ERROR DUE TO POOR ANALYSIS

DT 12Z 21/7/93

This case from July 93 when the model performance was again poor (see Figs V1,V2) shows a clear problem with the analysis of low level winds. The model incorrectly forecast a front and associated precipitation too far east . The position as shown by the 850mb wet bulb potential temperature gradient through Wales and into central England at only T+12 (Figure 36a) is clearly too advanced compared to the analysis for 00Z 22/7/93 (Figure 36b) and the gradient too strong. The 850mb level winds forecast winds are in excess of 5 m s^{-1} too large over Ireland and to the west (Fig 37a,b,c). The low level winds are responsible for the front being advected too fast and are overestimated at analysis time 12Z 21/7/93 (Fig 38). A poor analysis in a relatively data sparse area is responsible for a subsequent poor short period rainfall forecast.

FIGURES

Section 3

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Figure V2	Verification for UK area DT 12UTC: monthly % correct and % nil observed st T+24
Figure V3	Verification for UK area DT 00UTC and DT12UTC: monthly % correct at T+24
Figure V4	Verification for UK area DT 00UTC: bias every 6h period for May -Dec 92 ("winter" months have symbols)
Figure V5	Verification for UK area DT 12UTC: bias every 6h period for May -Dec 92 ("winter" months have symbols)
Figure V6	Verification for UK area DT 00UTC: bias every 6h period for Feb-Aug 93 ("winter" months have symbols)
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Figure 2 b,d	New version (op-new) rainfall forecast for T+24/30 verifying at 12Z/18Z 02/05/92.
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Figure 4 a,c	Operational (op-old) rainfall forecast for T+12/18 verifying at 12Z/18Z 10/08/92.
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12Z/18Z 10/08/92.

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Figure 6 a,b,c — (a)Analysis 12Z 18/09/92 (b,c) radar images for 06Z/12Z 18/09/92.
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Figure 19 — Limited area forecast for T+48-T+60, rerun from global analysis DT12Z 06/08/92
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Figure 37c	wind error for 850mb valid at 00Z 22/7/93 : T+12 - verifying analysis T+0
Figure 38	Wet bulb potential temperature and winds for 850mb valid at 12Z 21/7/93 : analysis T+0

Figure V1

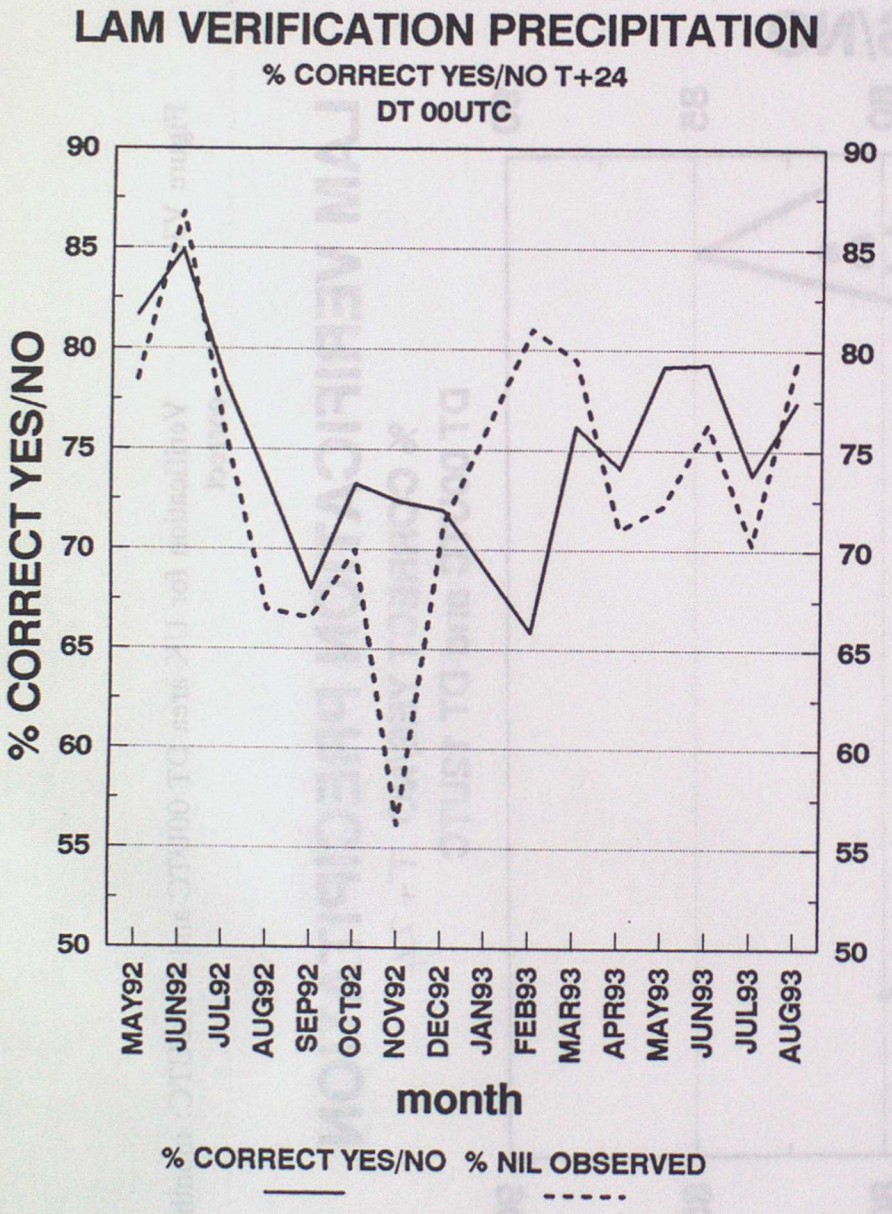


Figure V2

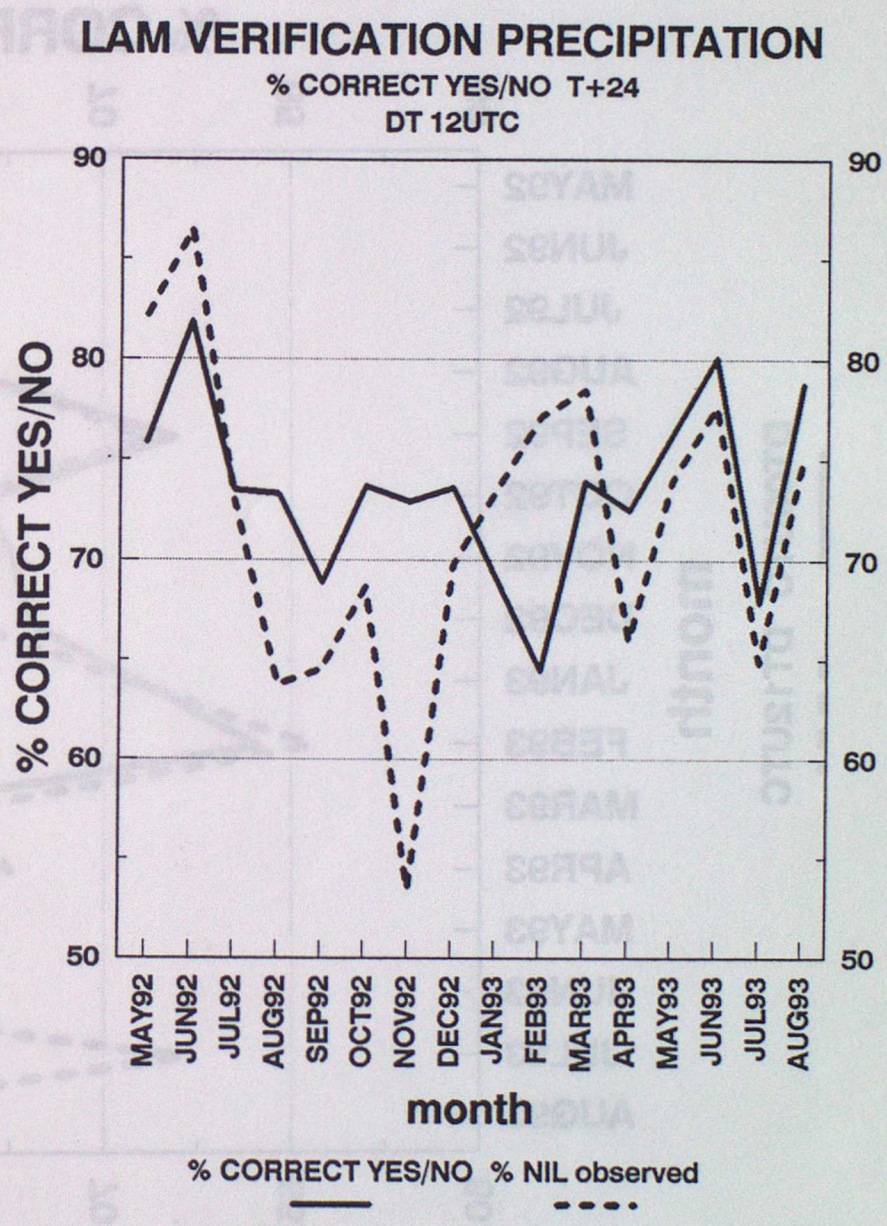


Figure V3 Verification for UK area DT 00UTC and DT12UTC: monthly % correct

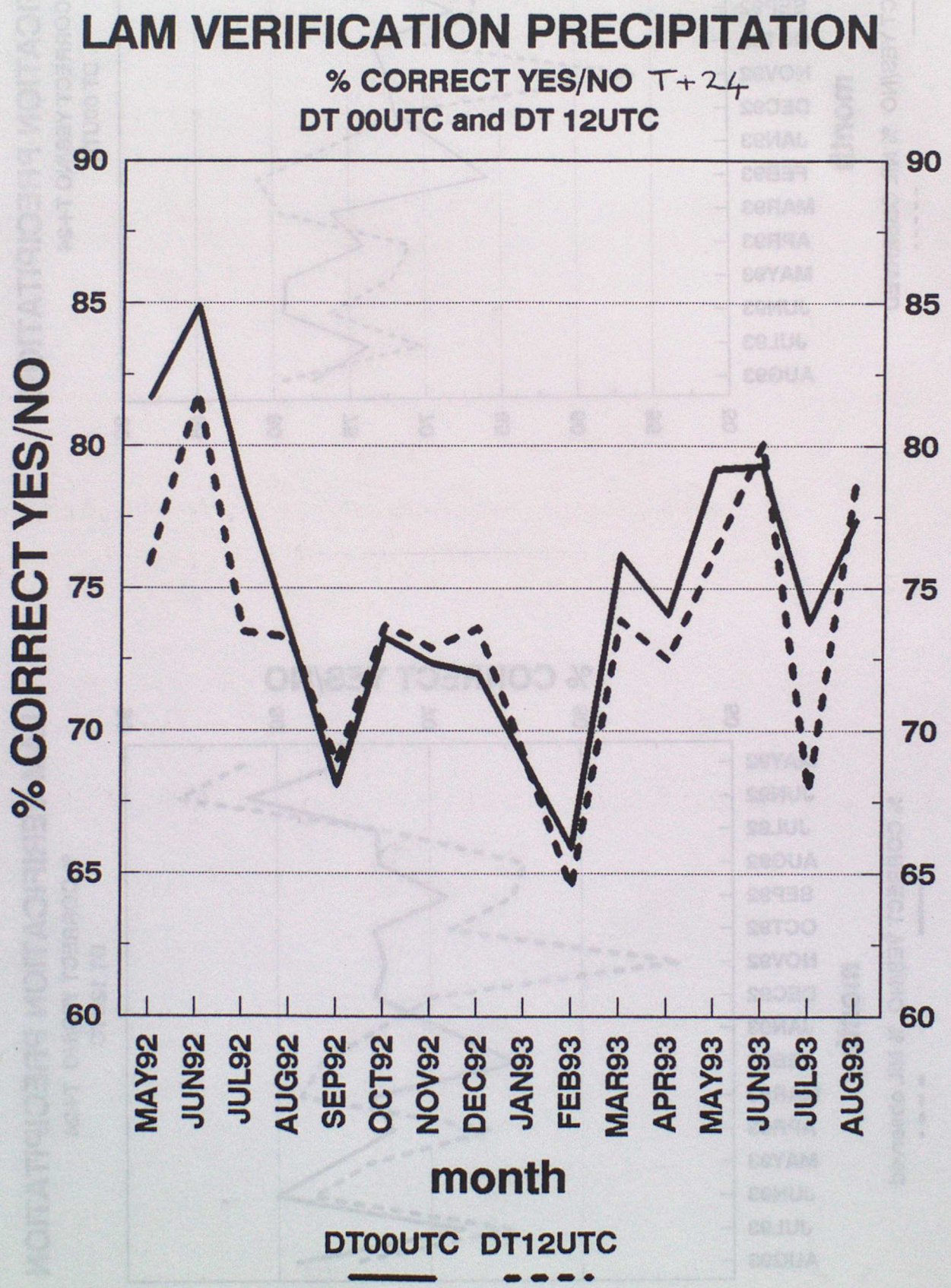
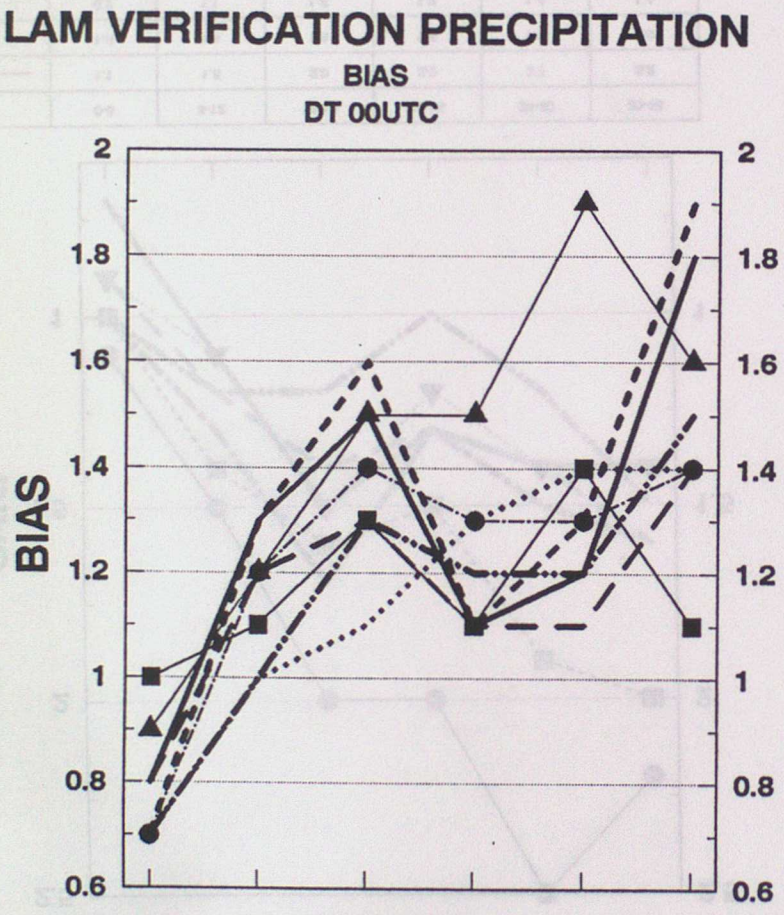


Figure V4

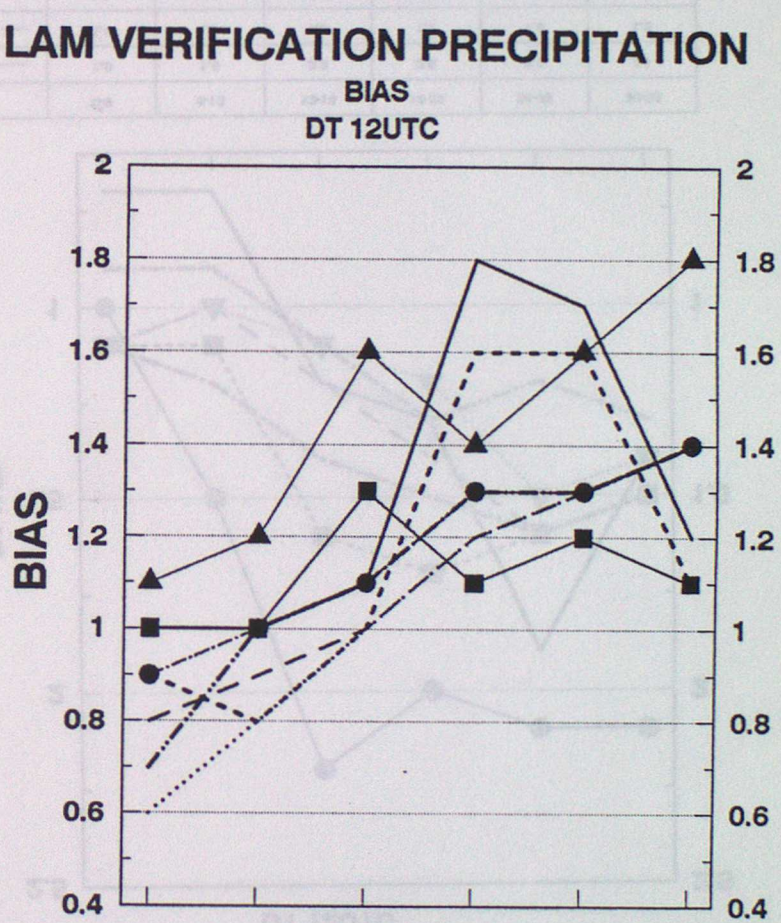
Verification for UK area DT 00UTC: bias every 6h period for May -Dec 92 ("winter" months have symbols)



PERIOD	0-6	6-12	12-18	18-24	24-30	30-36
MAY92	0.8	1.3	1.5	1.1	1.2	1.8
JUN92	0.7	1.3	1.6	1.1	1.3	1.9
JUL92	0.7	1.0	1.1	1.3	1.4	1.4
AUG92	0.8	1.2	1.3	1.1	1.1	1.4
SEP92	0.7	1.0	1.3	1.2	1.2	1.5
OCT92	0.7	1.2	1.4	1.3	1.3	1.4
NOV92	1.0	1.1	1.3	1.1	1.4	1.1
DEC92	0.9	1.2	1.5	1.5	1.9	1.6

Figure V5

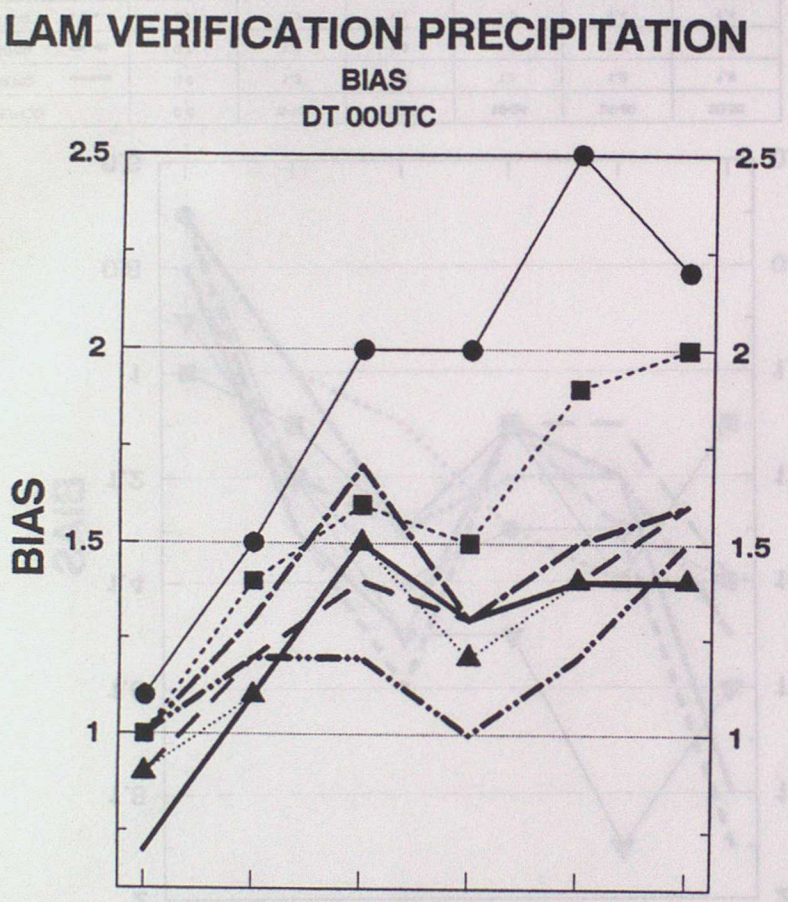
Verification for UK area DT 12UTC: bias every 6h period for M -Dec 92 ("winter" months have symbols)



PERIOD	0-6	6-12	12-18	18-24	24-30	30-36
MAY92	1.0	1.0	1.1	1.8	1.7	1.2
JUN92	0.9	0.8	1.0	1.6	1.6	1.1
JUL92	0.6	0.8	1.0	1.2	1.3	1.4
AUG92	0.8	0.9	1.0	1.2	1.3	1.4
SEP92	0.7	1.0	1.1	1.3	1.3	1.4
OCT92	0.9	1.0	1.1	1.3	1.3	1.4
NOV92	1.0	1.0	1.3	1.1	1.2	1.1
DEC92	1.1	1.2	1.6	1.4	1.6	1.8

Figure V6

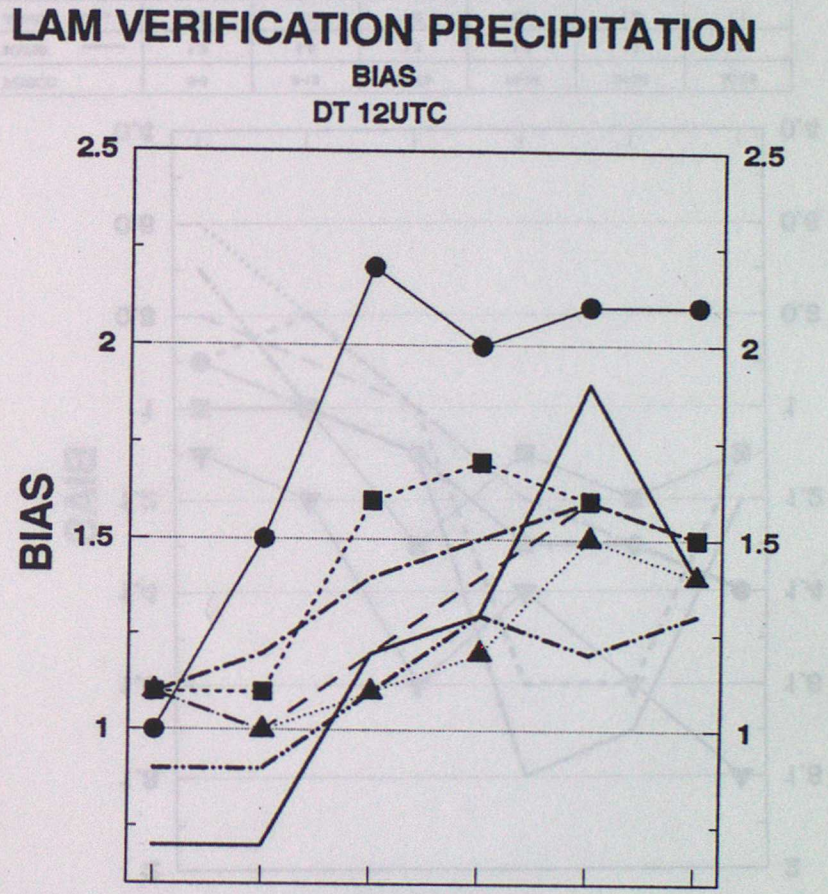
Verification for UK area DT 00UTC: bias every 6h period for Feb-Aug 93 ("winter" months have symbols)



PERIOD	0-6	6-12	12-18	18-24	24-30	30-36
FEB93 ——	1.1	1.5	2.0	2.0	2.5	2.2
MAR93 - - - -	1.0	1.4	1.6	1.5	1.9	2.0
APR93	0.9	1.1	1.5	1.2	1.4	1.4
MAY93 ——	0.9	1.2	1.4	1.3	1.4	1.6
JUN93 —•—	1.0	1.2	1.2	1.0	1.2	1.5
JUL93 —•—	1.0	1.3	1.7	1.3	1.5	1.6
AUG93 ——	0.7	1.1	1.5	1.3	1.4	1.4

Figure V7

Verification for UK area DT 12UTC: bias every 6h period for Feb - Aug 93 ("winter" months have symbols)



PERIOD	0-6	6-12	12-18	18-24	24-30	30-36
FEB93 ——	1.0	1.5	2.2	2.0	2.1	2.1
MAR93 - - - -	1.1	1.1	1.6	1.7	1.6	1.5
APR93	1.1	1.0	1.1	1.2	1.5	1.4
MAY93 ——	1.1	1.0	1.2	1.4	1.6	1.5
JUN93 —••—	0.9	0.9	1.1	1.3	1.2	1.3
JUL93 —•—	1.1	1.2	1.4	1.5	1.6	1.5
AUG93 ——	0.7	0.7	1.2	1.3	1.9	1.4

Figure V8

Verification for UK area DT 00UTC: mean summer and winter biases every 6h period ("winter" means have symbols)

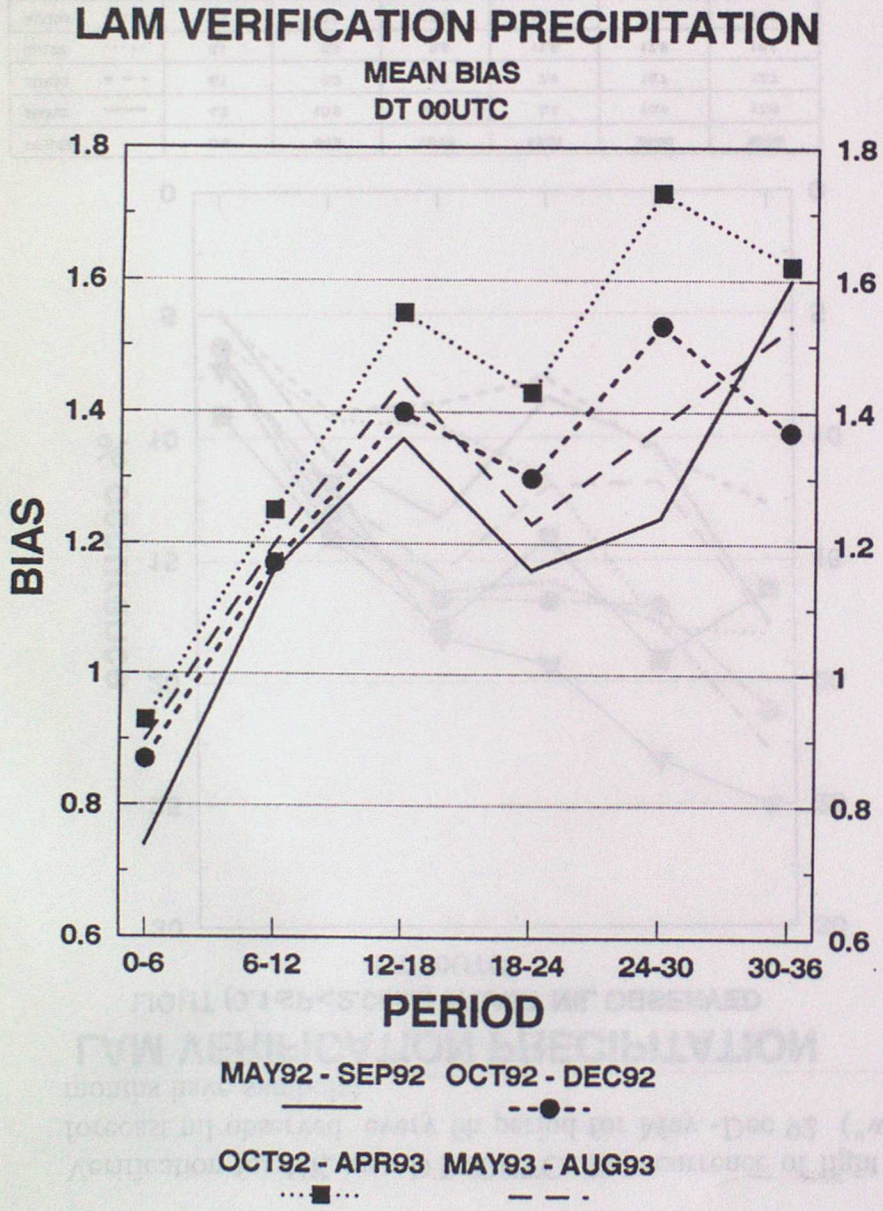


Figure V9

Verification for UK area DT 12UTC: mean summer and winterbiases every 6h period ("winter" means have symbols)

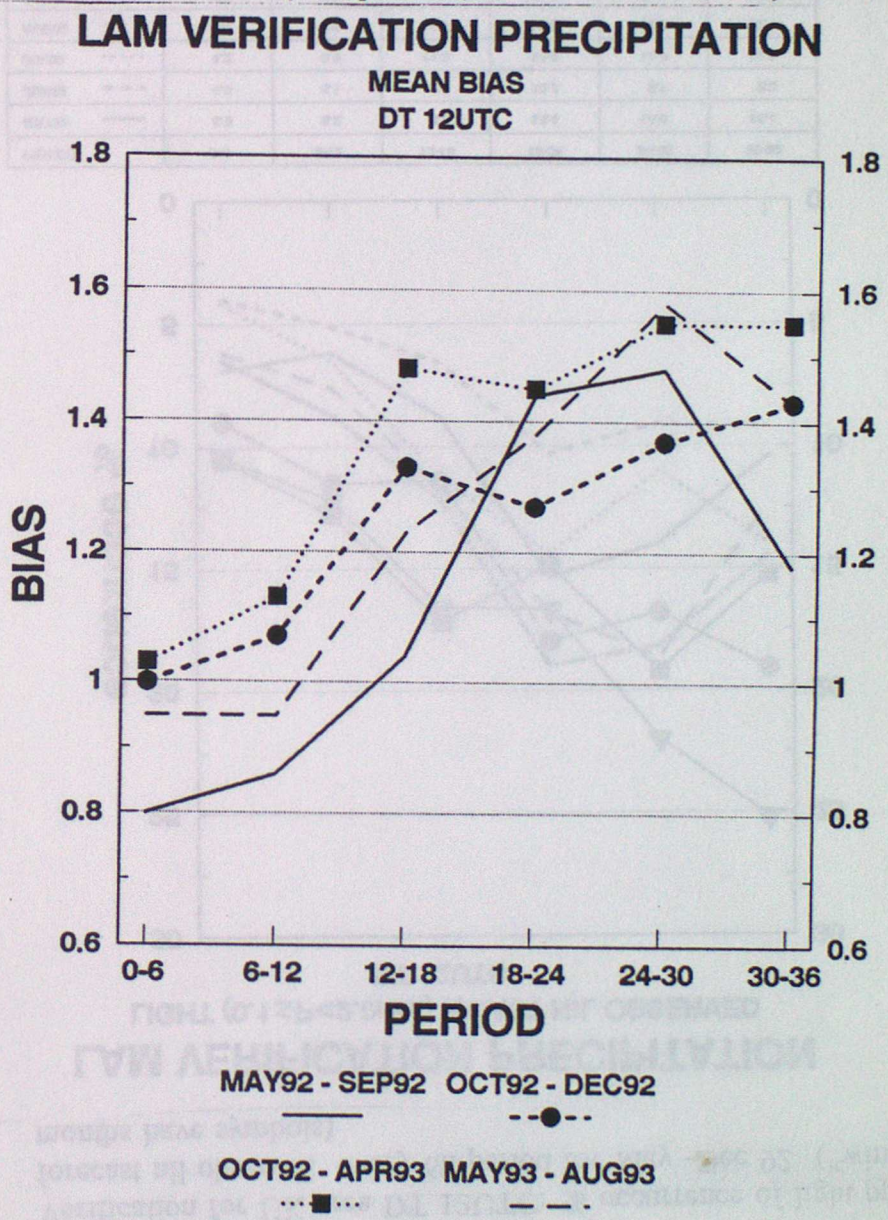
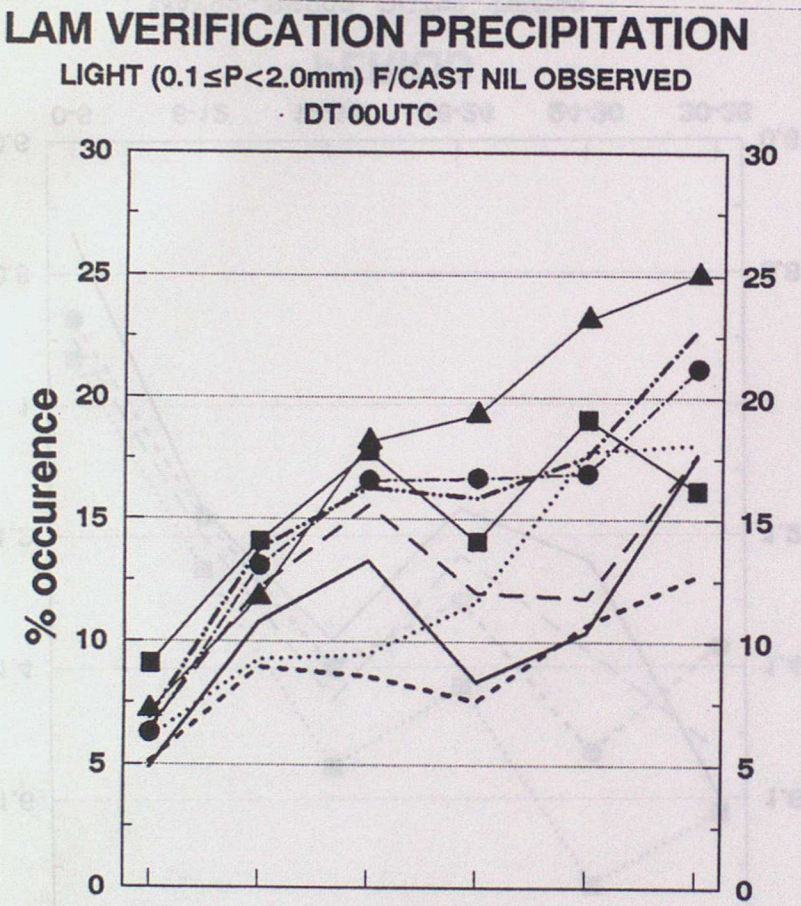


Figure V10

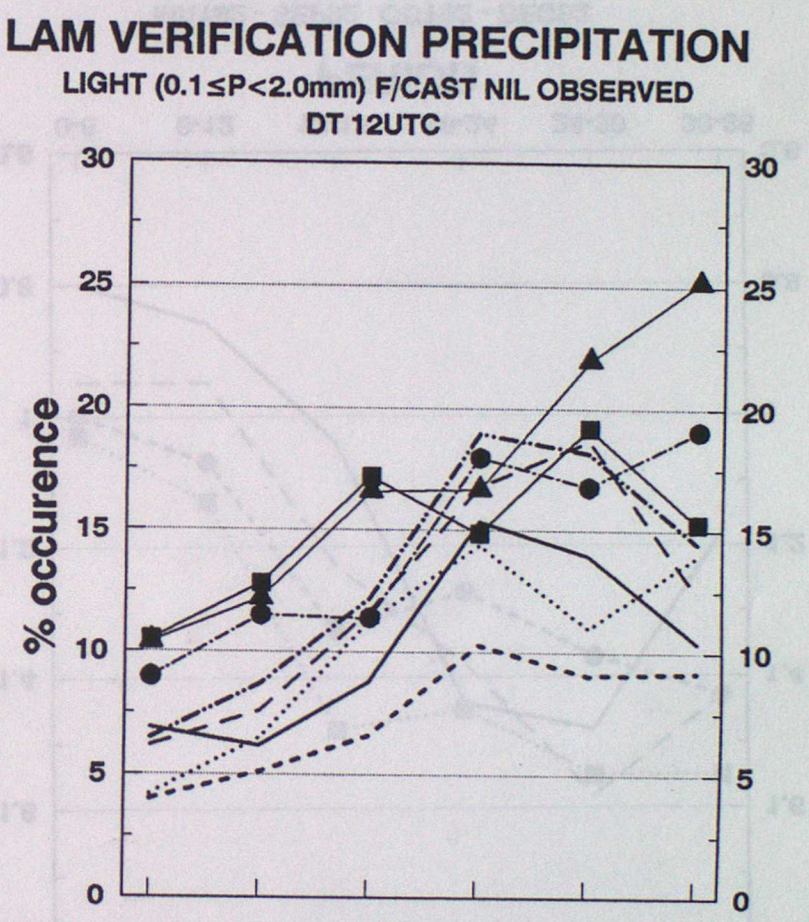
Verification for UK area DT 00UTC: % occurrence of light pptn forecast nil observed every 6h period for May -Dec 92 ("winter" months have symbols)



PERIOD	0-6	6-12	12-18	18-24	24-30	30-36
MAY92 ——	4.9	10.8	13.3	9.4	10.4	17.6
JUN92 – – –	5.1	9.0	8.6	7.6	10.7	12.7
JUL92 ·····	6.1	9.3	9.5	11.6	17.8	18.1
AUG92 — ·	6.5	12.2	15.6	12.0	11.8	17.7
SEP92 —···	6.9	13.8	16.3	15.9	17.6	22.8
OCT92 —·—	6.3	13.1	16.6	16.7	16.9	21.2
NOV92 ——	9.1	14.1	17.8	14.1	19.1	16.2
DEC92 ——	7.2	11.8	16.2	19.3	23.2	25.0

Figure V11

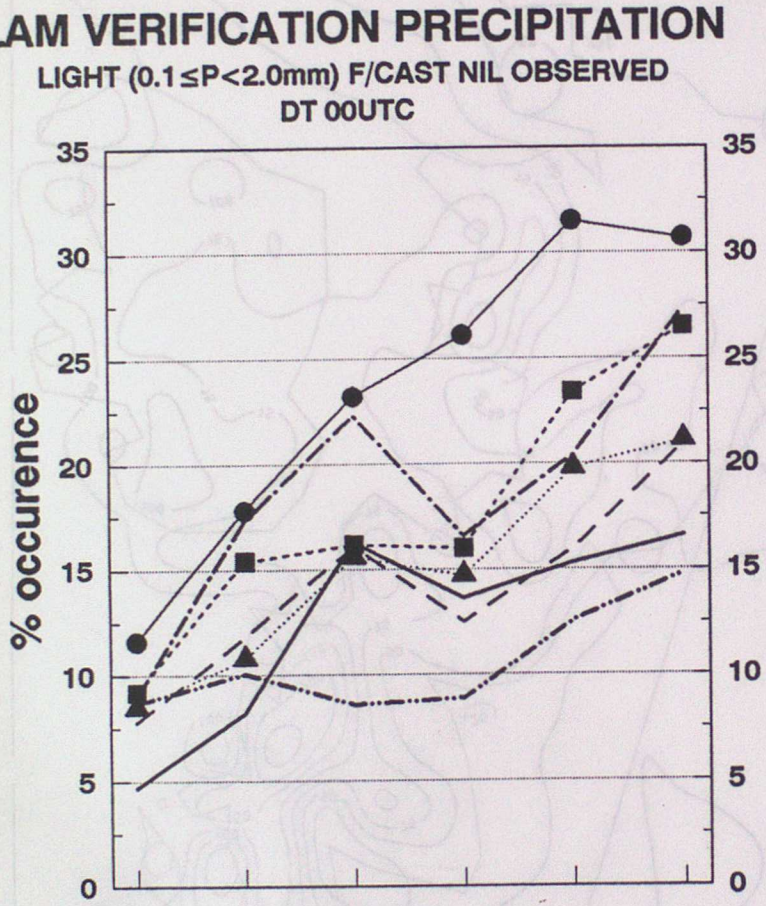
Verification for UK area DT 12UTC: % occurrence of light pptn forecast nil observed every 6h period for May -Dec 92 ("winter" months have symbols)



PERIOD	0-6	6-12	12-18	18-24	24-30	30-36
MAY92 ——	6.9	8.2	8.8	15.4	14.0	10.4
JUN92 – – –	4.0	5.1	6.6	10.3	9.1	9.2
JUL92 ·····	4.2	6.5	11.3	14.4	11.0	14.0
AUG92 — ·	6.2	7.6	11.7	16.9	18.7	12.4
SEP92 —···	6.5	8.7	12.2	19.0	18.2	14.5
OCT92 —·—	9.0	11.5	11.4	18.0	16.8	19.1
NOV92 ——	10.5	12.8	17.2	14.9	19.2	15.3
DEC92 ——	10.4	12.2	16.6	16.7	22.0	25.2

Figure V12

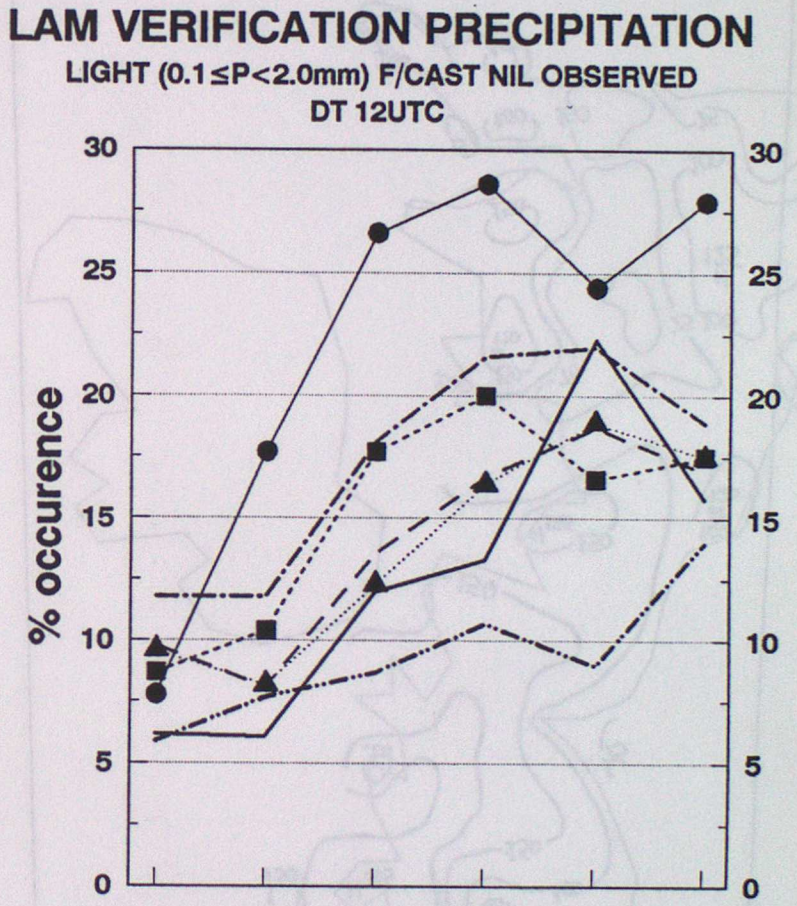
Verification for UK area DT 00UTC:% occurrence of light pptn forecast nil observed every 6h period for Feb - Aug 93 ("winter" months have symbols)



PERIOD		0-6	6-12	12-18	18-24	24-30	30-36
FEB93	——	11.6	17.8	23.2	26.1	31.5	30.7
MAR93	- - - -	9.2	15.4	16.2	16.0	23.4	26.5
APR93	.....	8.5	10.8	15.6	14.7	19.8	21.1
MAY93	— .	7.8	11.8	16.1	12.5	16.0	20.9
JUN93	—...	8.7	10.1	8.6	8.9	12.6	14.8
JUL93	—..	9.0	17.3	22.3	16.6	20.4	27.3
AUG93	——	4.7	8.2	16.3	13.6	15.3	16.6

Figure V13

Verification for UK area DT 12UTC: % occurrence of light pptn forecast nil observed every 6h period for Feb - Aug 93 ("winter" months have symbols)



PERIOD		0-6	6-12	12-18	18-24	24-30	30-36
FEB93	——	7.8	17.7	26.6	28.6	24.4	27.9
MAR93	- - - -	8.7	10.4	17.7	20.0	16.6	17.5
APR93	.....	9.6	8.2	12.3	16.4	18.9	17.5
MAY93	— .	9.8	8.1	13.6	16.7	18.7	16.9
JUN93	—...	5.9	7.7	8.7	10.7	9.0	14.0
JUL93	—..	11.8	11.8	16.1	21.6	22.0	18.9
AUG93	——	6.2	6.1	12.0	13.3	22.3	15.8

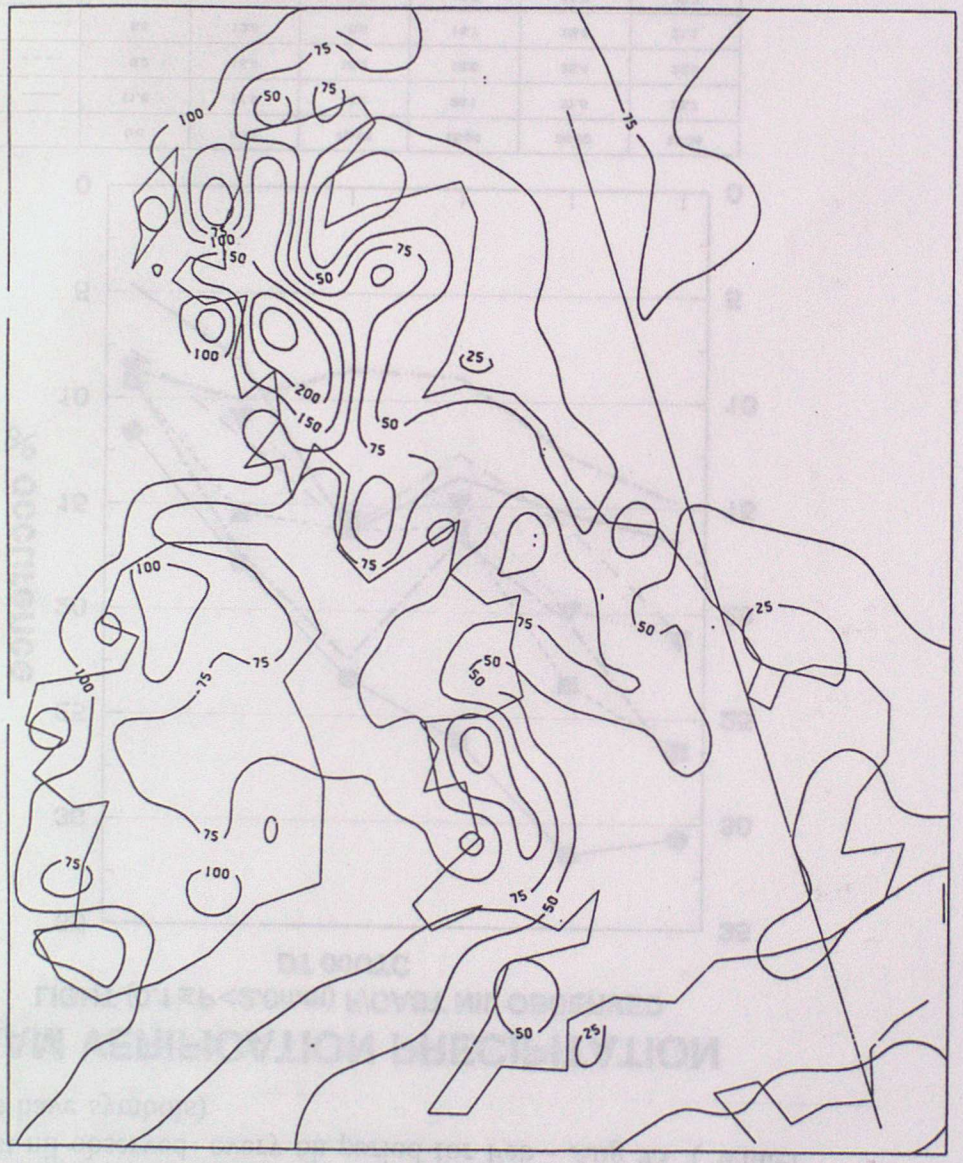


Figure V14

Total precipiation accumulated from T+0 to T+24 for September 1992

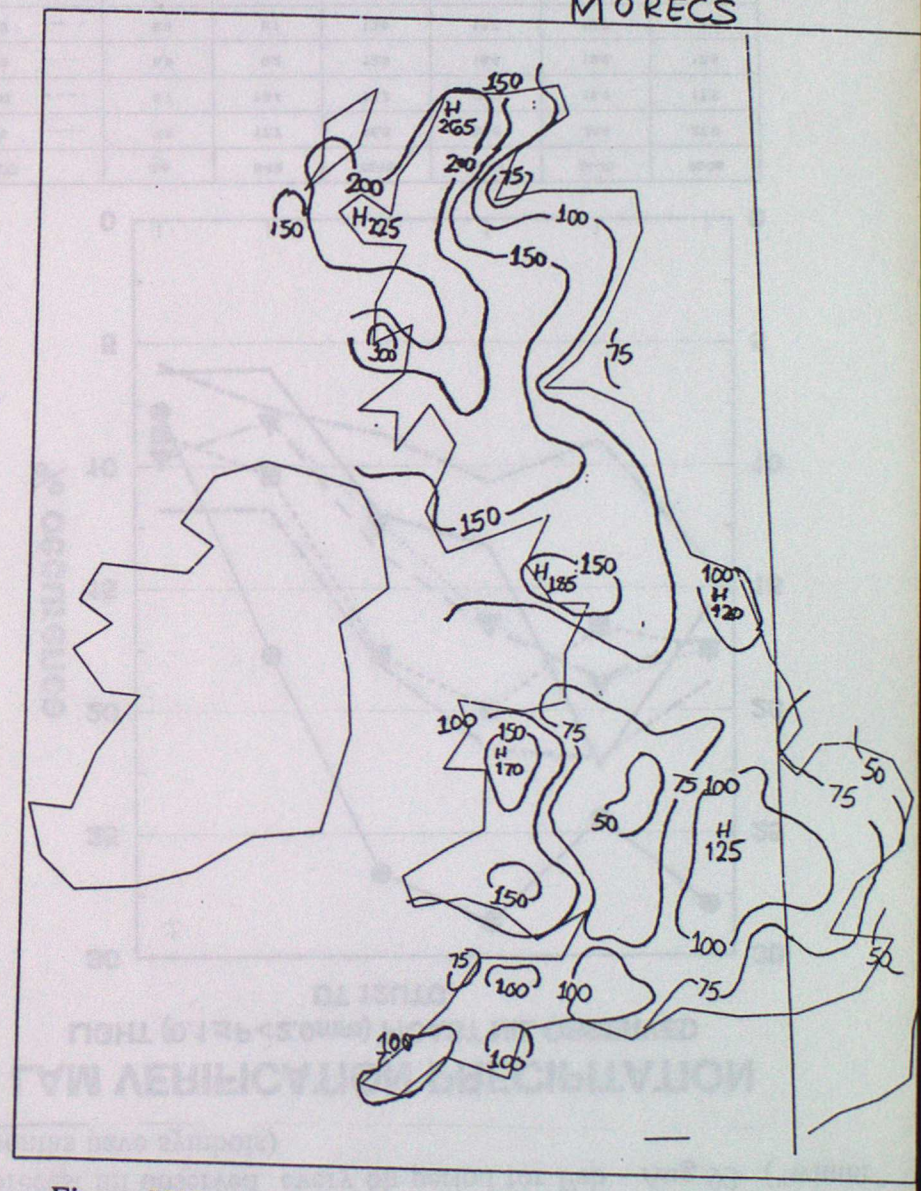
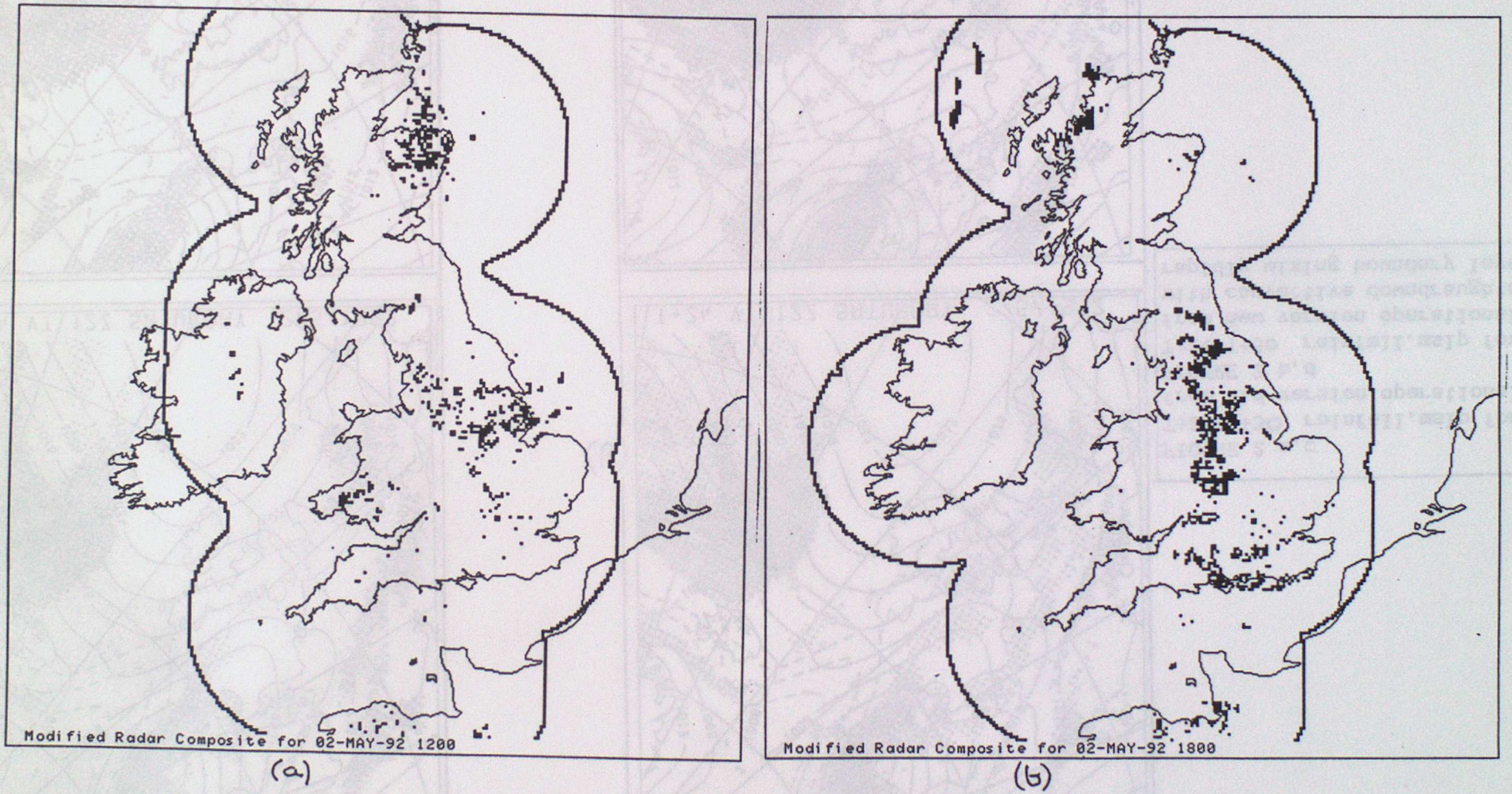


Figure V15

MORECS estimate of total precipitation for September 1992

Figure 1 a,b Radar images for 12Z/18Z 02/05/92



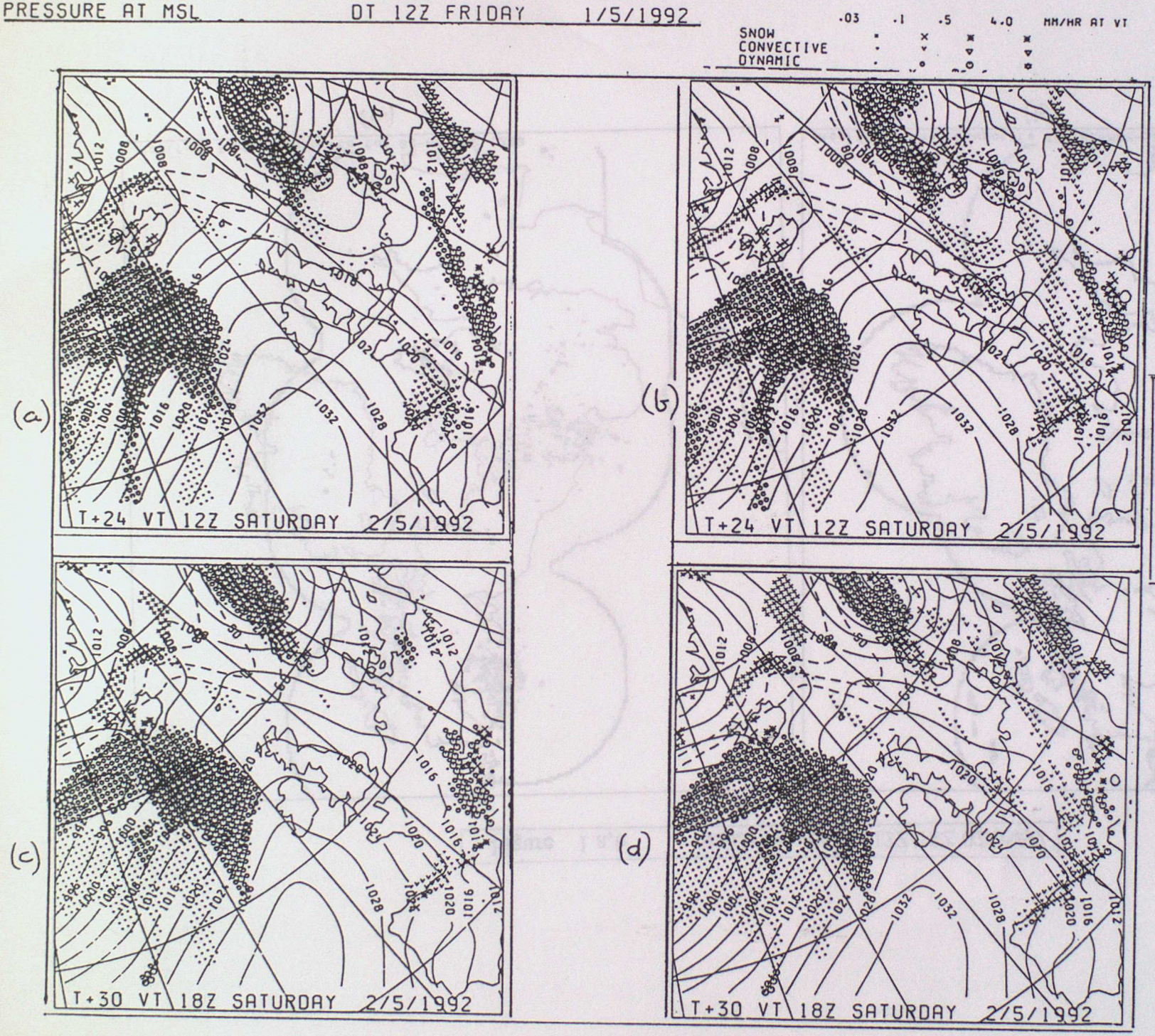
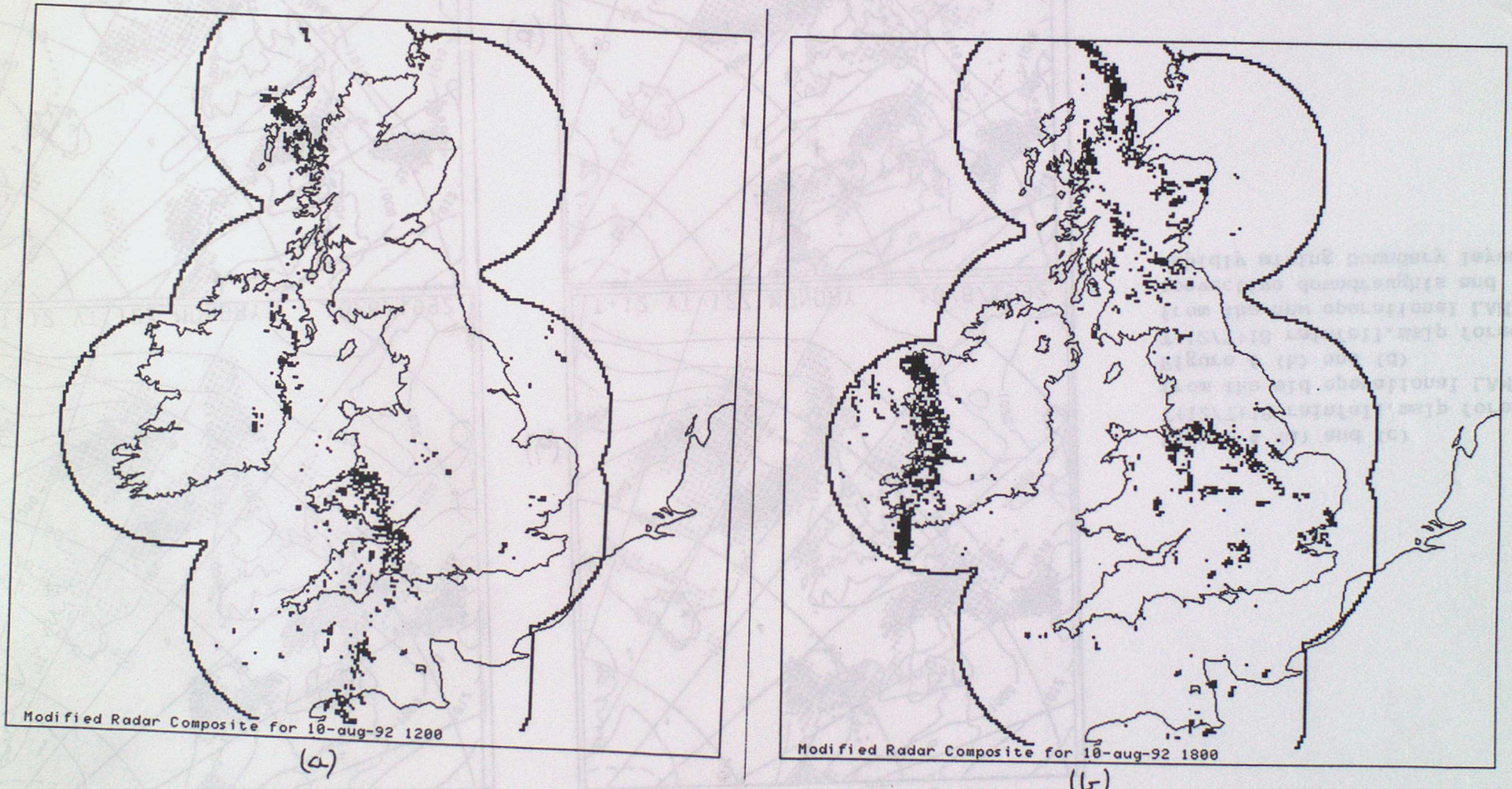


FIGURE 2 a,c
T+24/T+30 rainfall, mslp forecast from old version operational LAM
FIGURE 2 b,d
T+24/T+30 rainfall, mslp forecast from new version operational LAM with convective downdraughts and rapidly mixing boundary layer

Figure 3 (a) and (b)
Modified Radar Composites for 12Z and 18Z 10/08/92



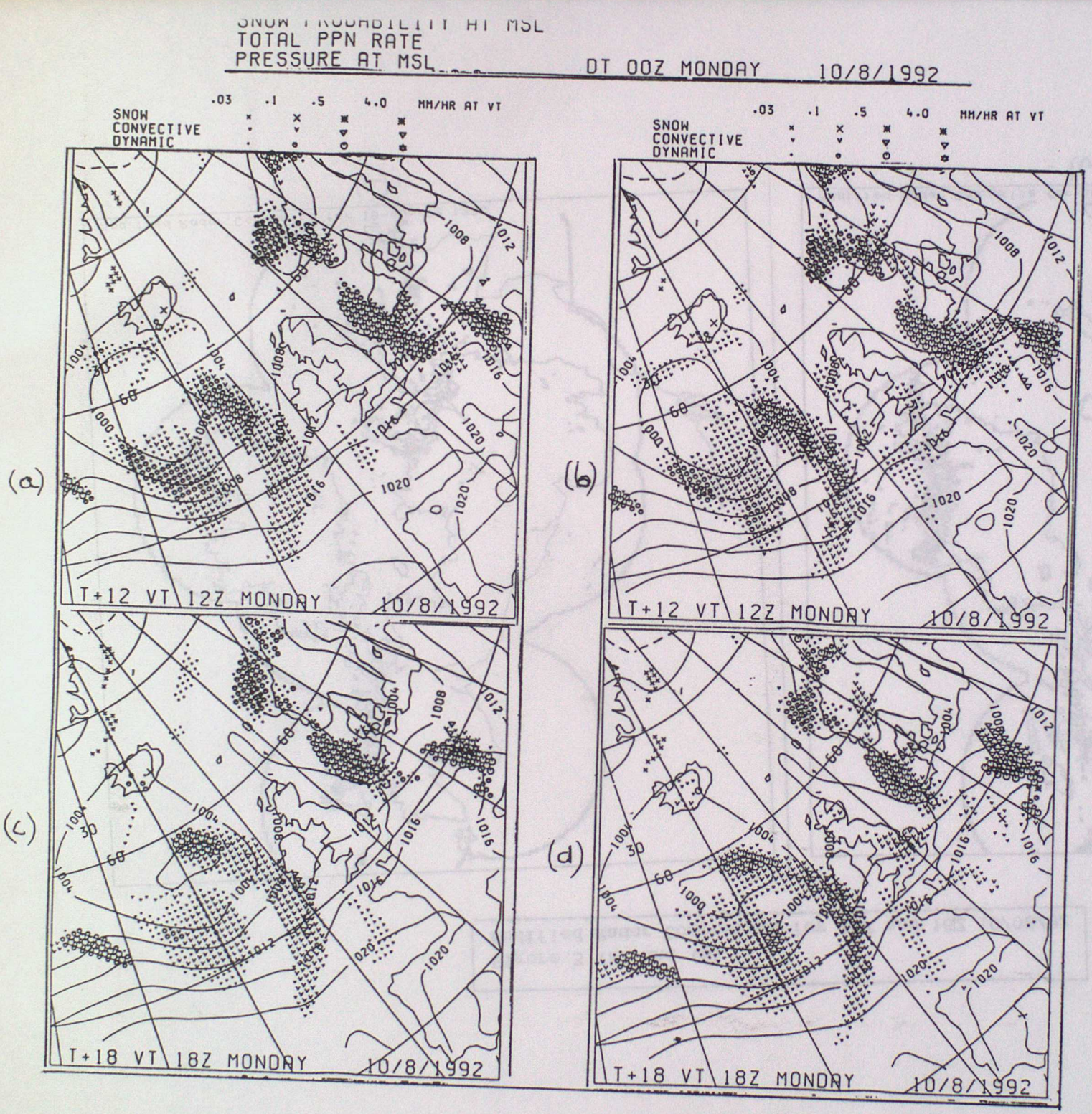
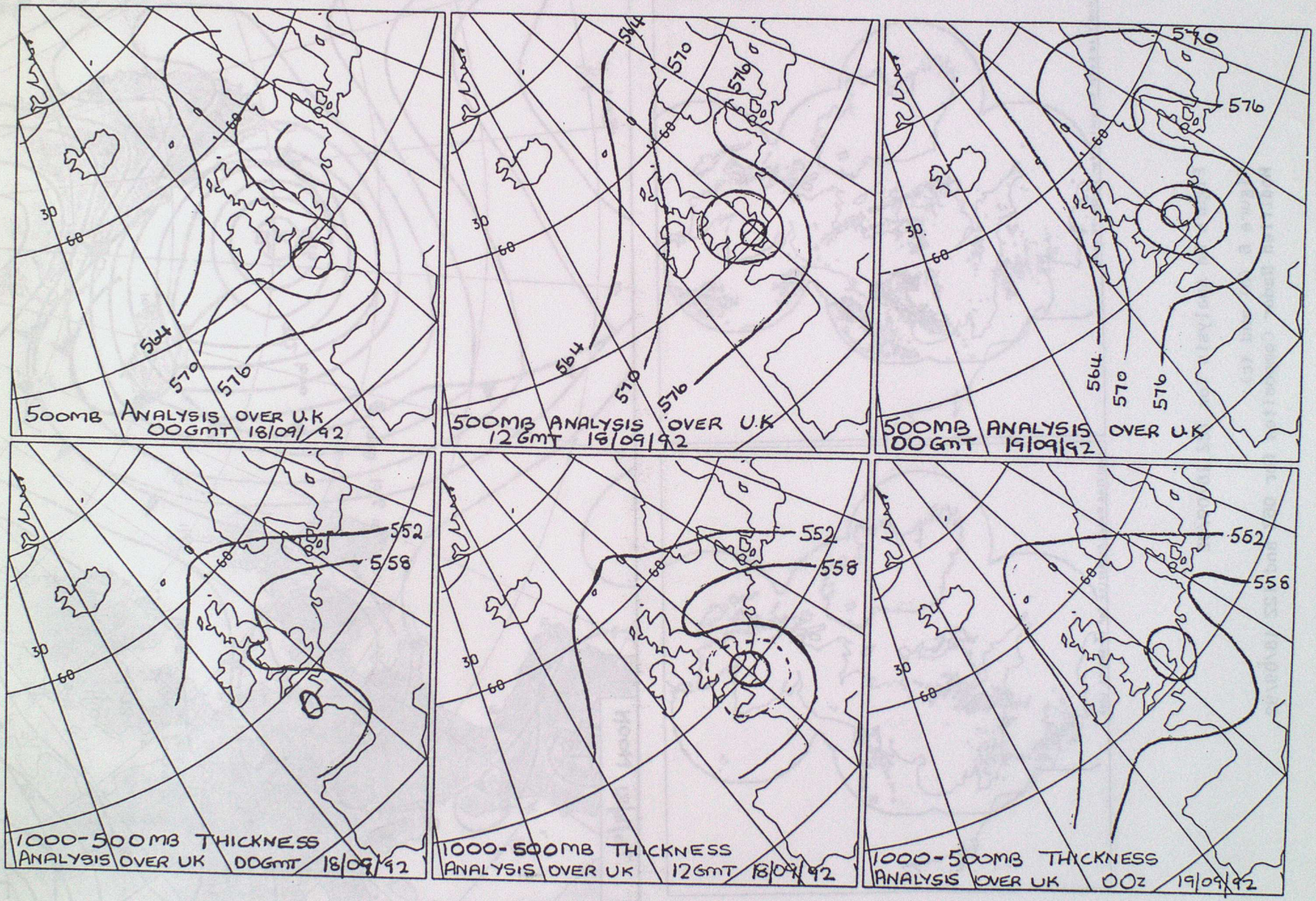
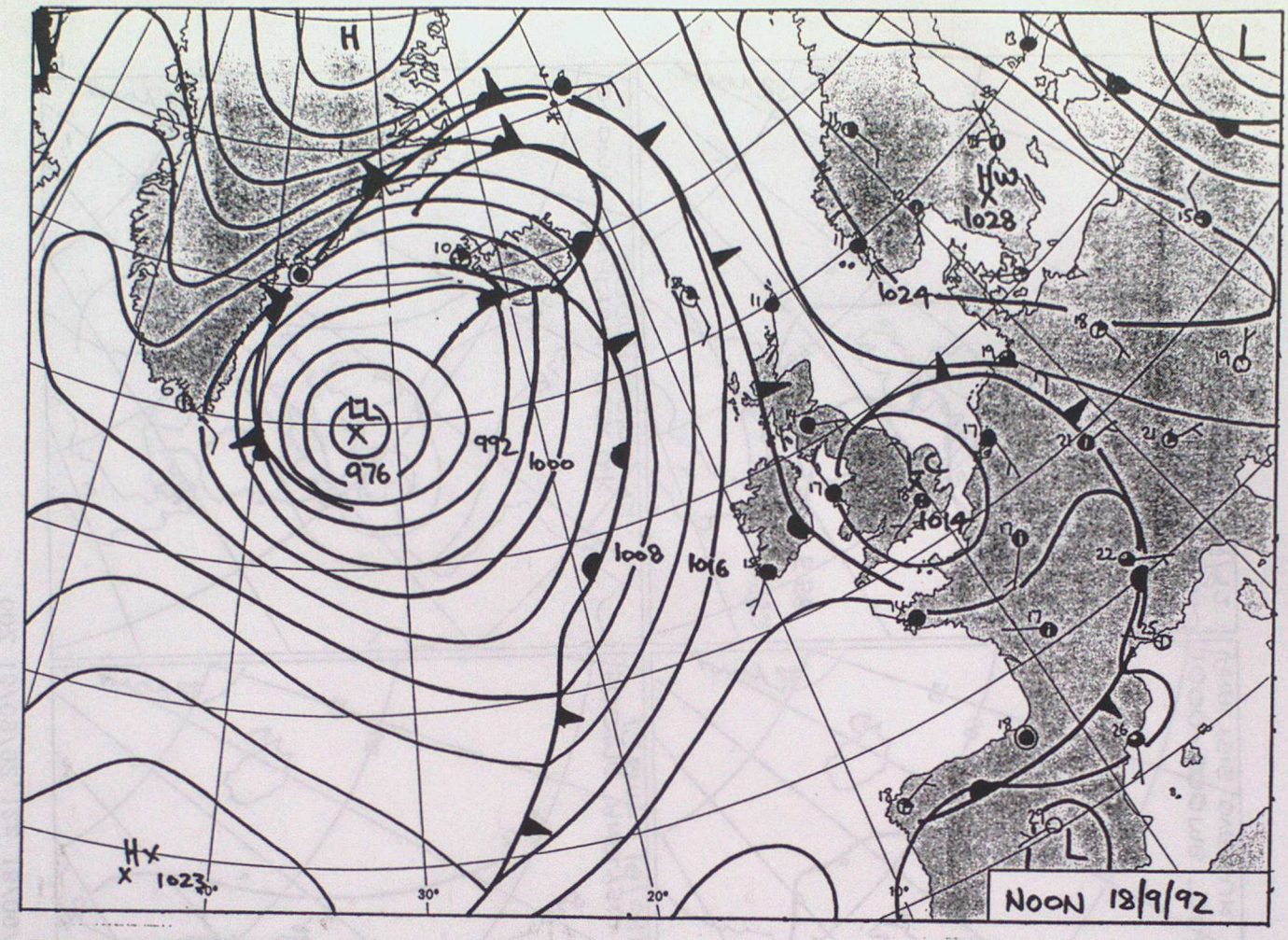


Figure 4 (a) and (c)
T+12/T+18 rainfall, mslp forecast from the old operational LAM
Figure 4 (b) and (d)
T+12/T+18 rainfall, mslp forecast from the new operational LAM with convective downdraughts and rapidly mixing boundary layer

Figure 5
500mb and 1000-500 thickness analyses for
00Z 18/09/92, 12z 18/09/92, 00Z 19/09/92





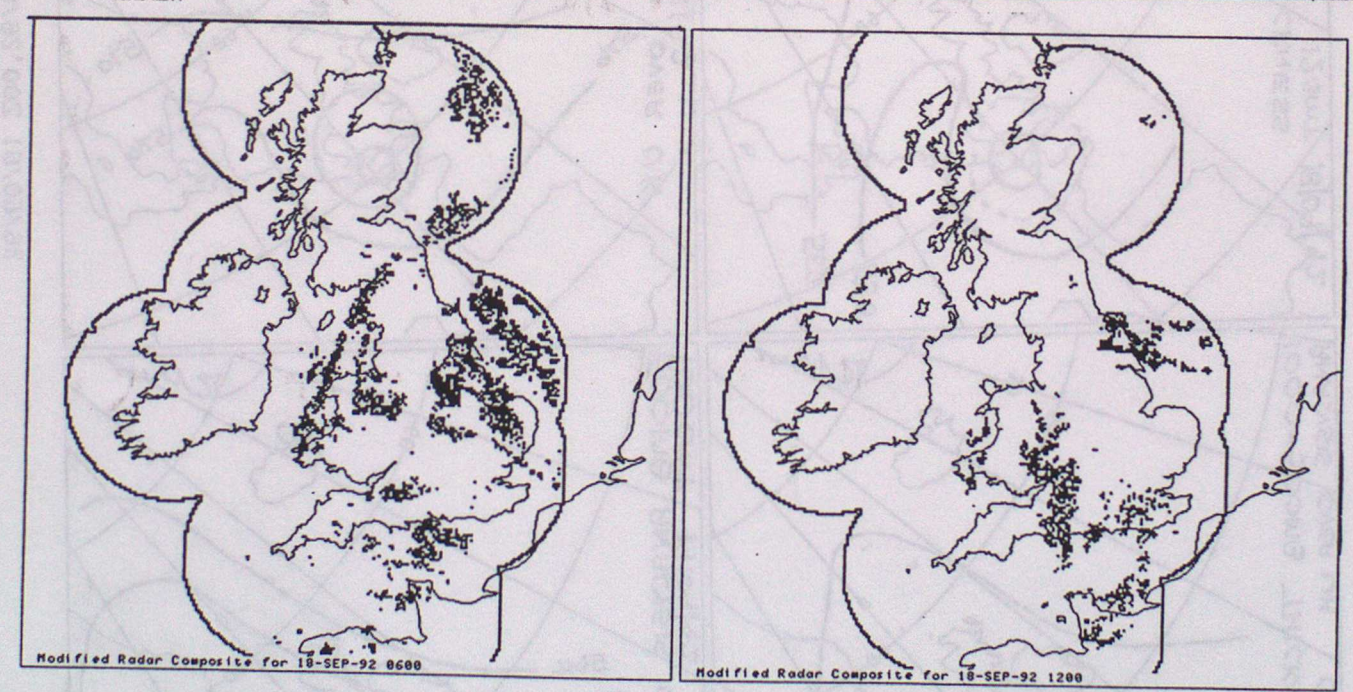


Figure 6a Analysis for 12Z 18/09/92

Figure 6 (b) and (c)
Modified Radar Composites for 06Z and 12Z 18/09/92

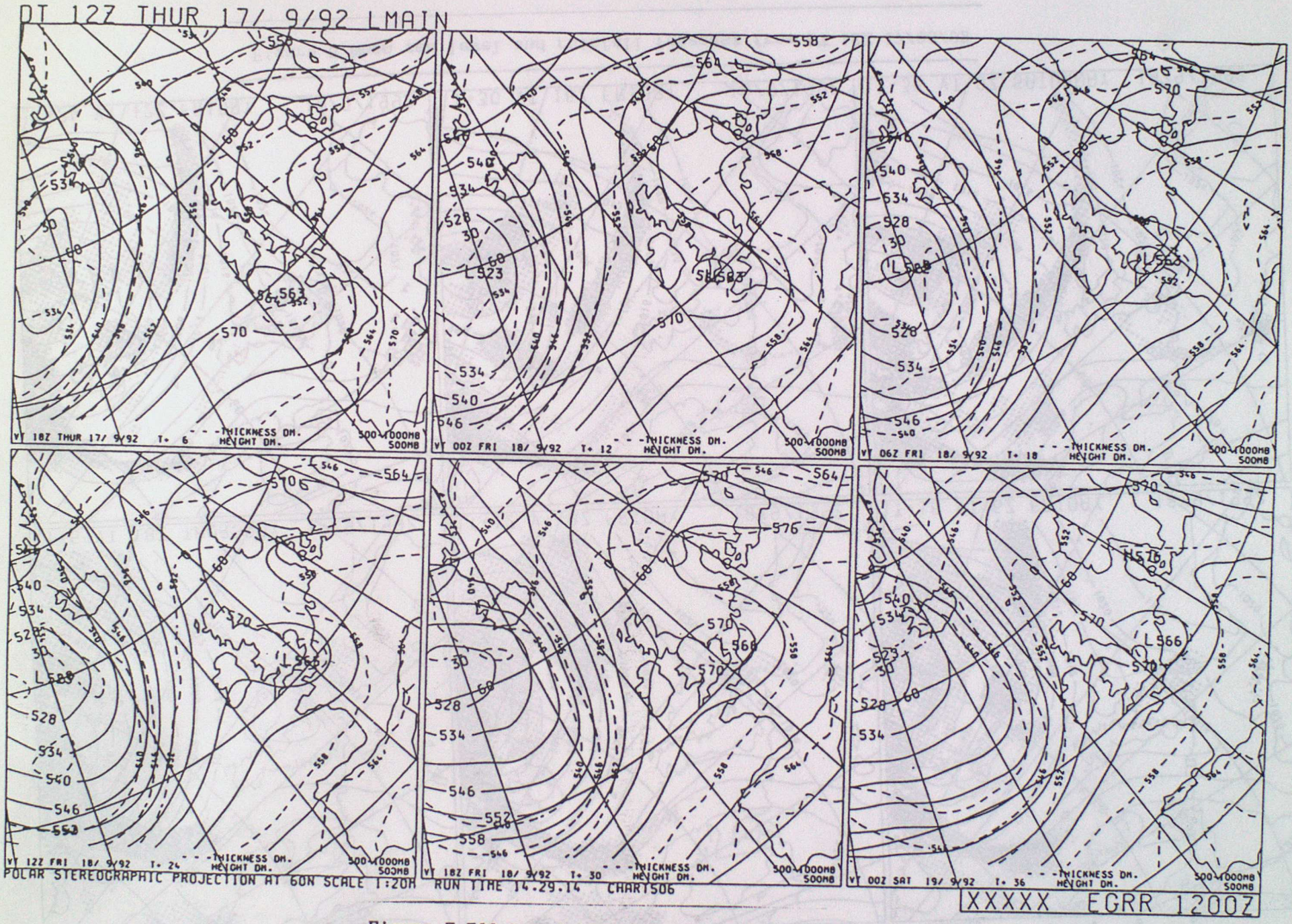


Figure 7 500mb and 1000-500mb thickness forecast from DT 12Z 17/09/92

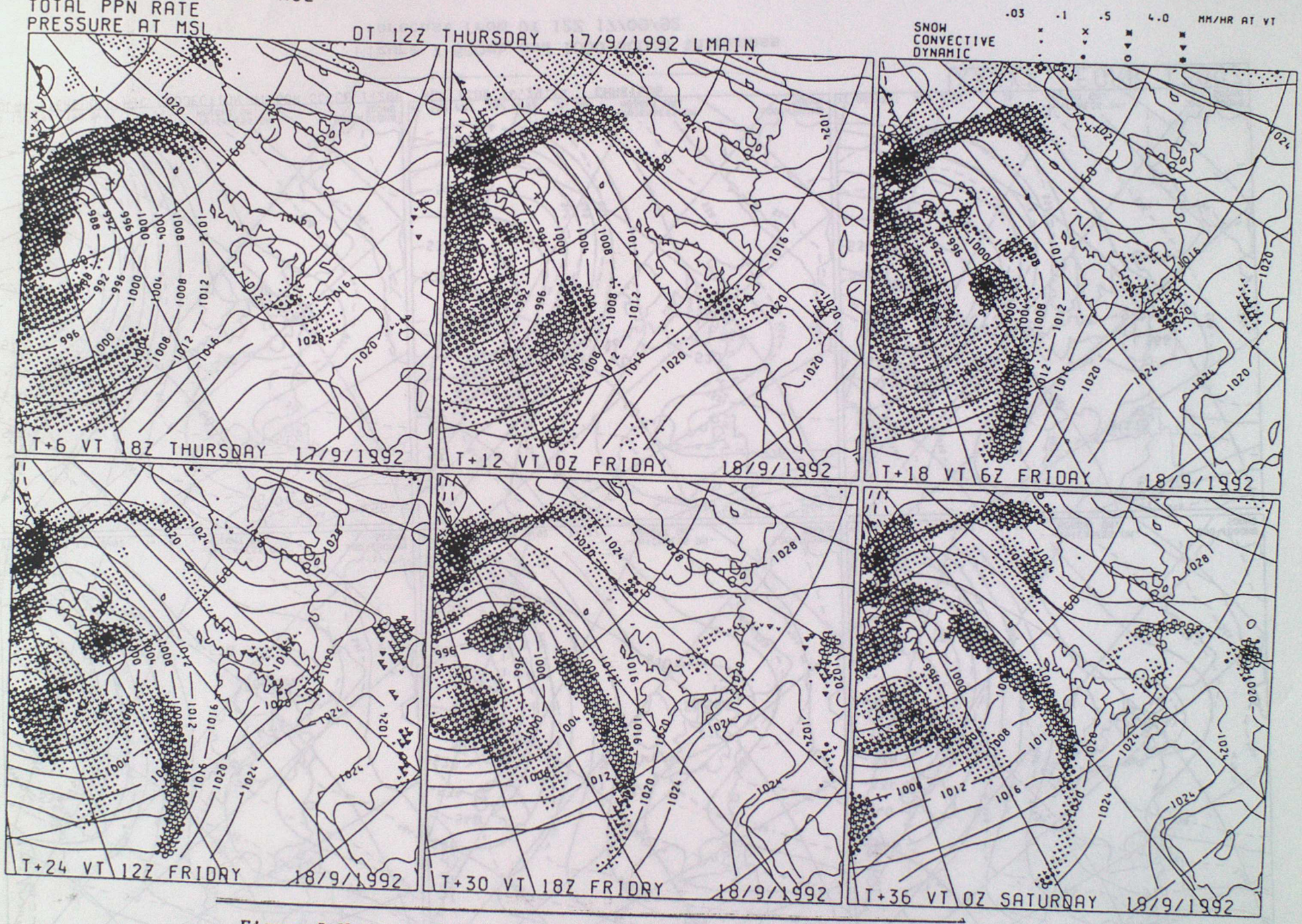
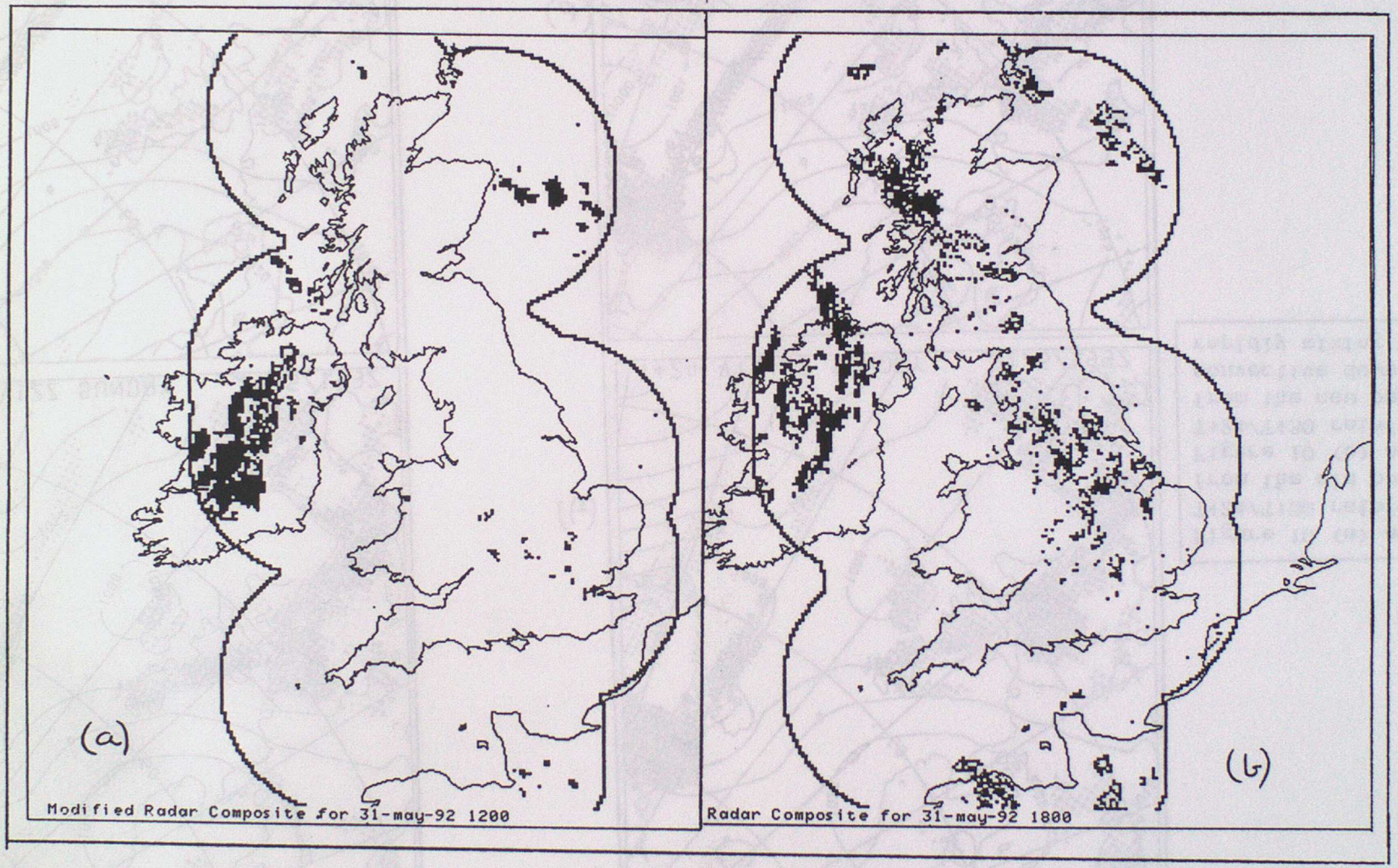


Figure 8 Mean sea level and rainfall forecast from DT 12Z 17/09/92

Figure 9 (a) and (b)
Modified Radar Composites for 12Z and 18Z 31/05/92



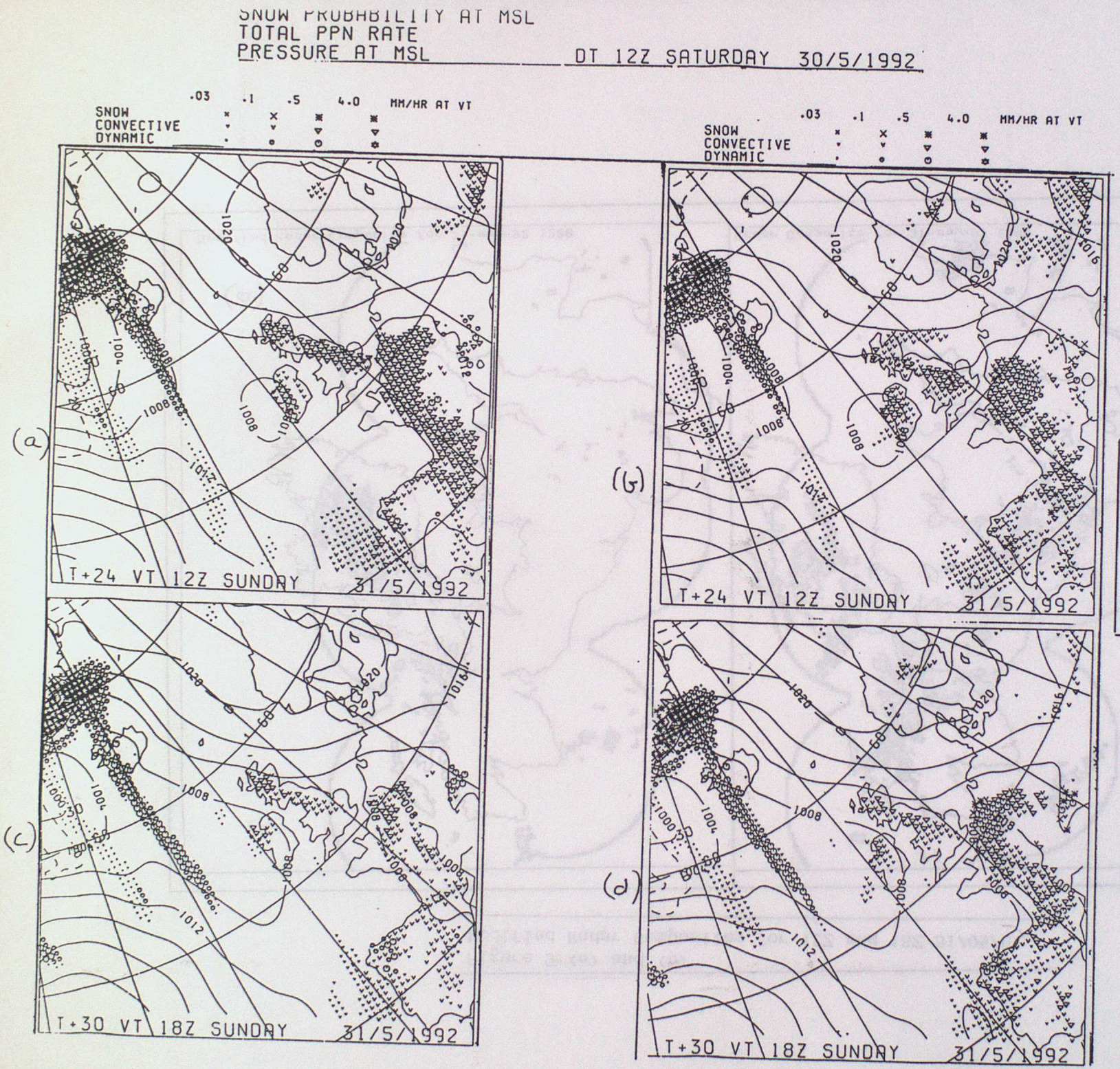
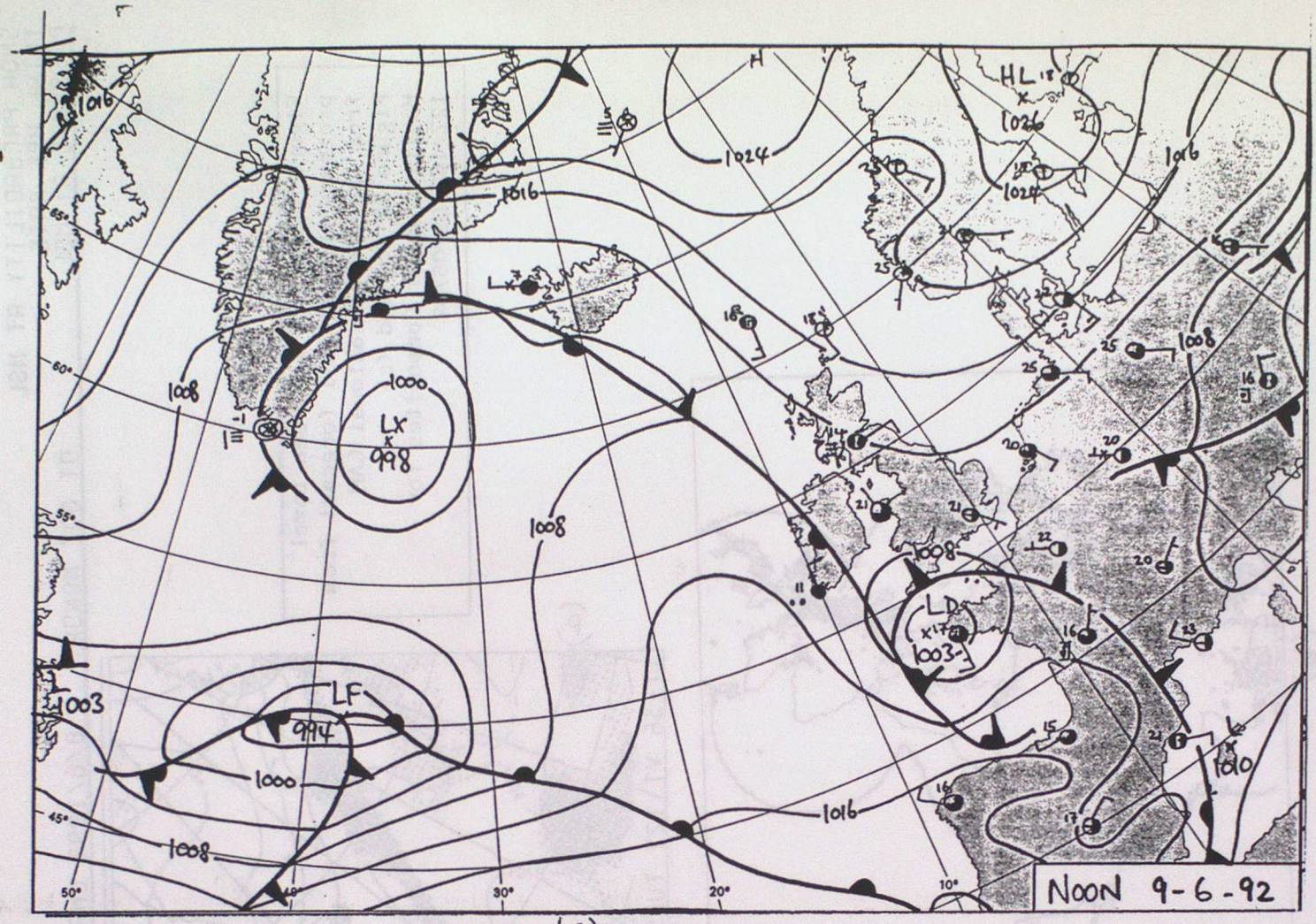
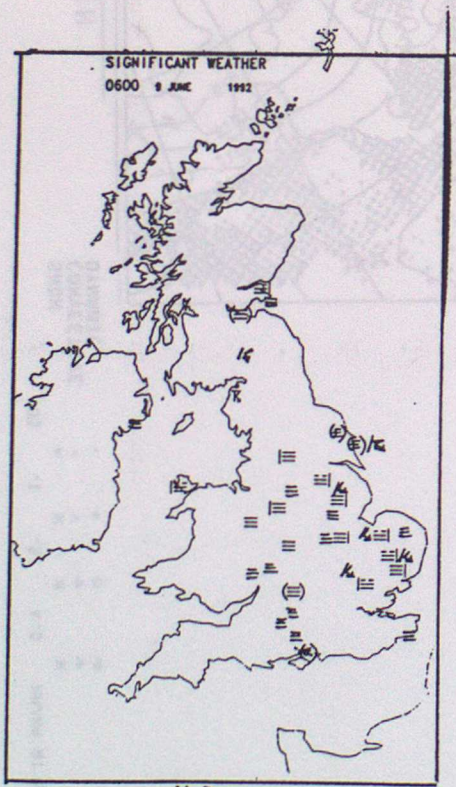


Figure 10 (a) and (c)
T+24/T+30 rainfall, mslp forecast from the old operational LAM
Figure 10 (b) and (d)
T+24/T+30 rainfall, mslp forecast from the new operational LAM with convective downdraughts and rapidly mixing boundary layer

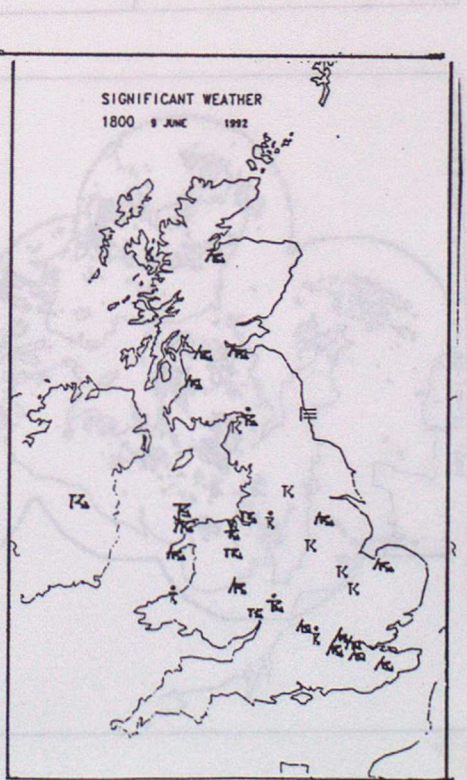


(a)



(b)

(c)



(d)

Figure 11(a) Analysis for 12Z 09/06/92
Figure 11 (b,c,d) Significant Weather Charts for 06Z, 12Z and 18Z 09/06/92

SNOW PROBABILITY AT MSL
TOTAL PPN RATE
PRESSURE AT MSL

DT OOZ MONDAY 8/6/1992 LMAIN

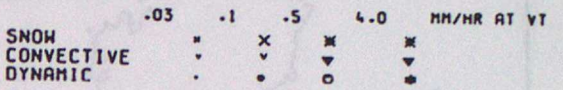
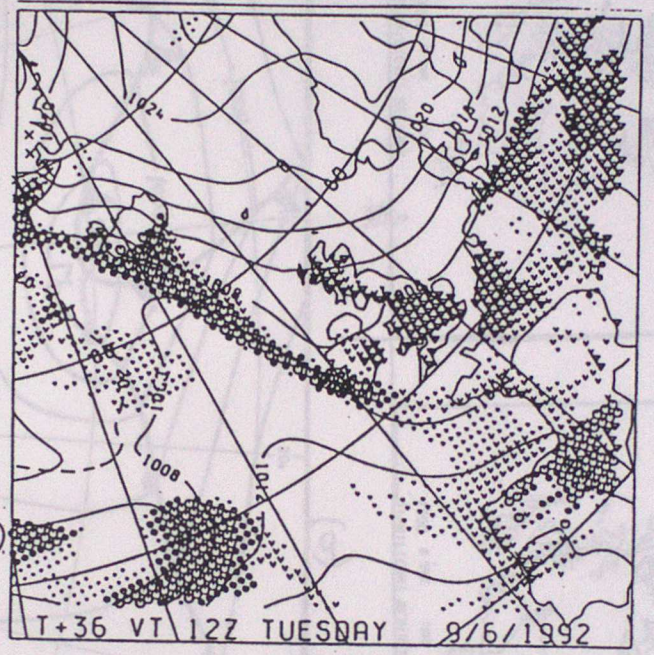
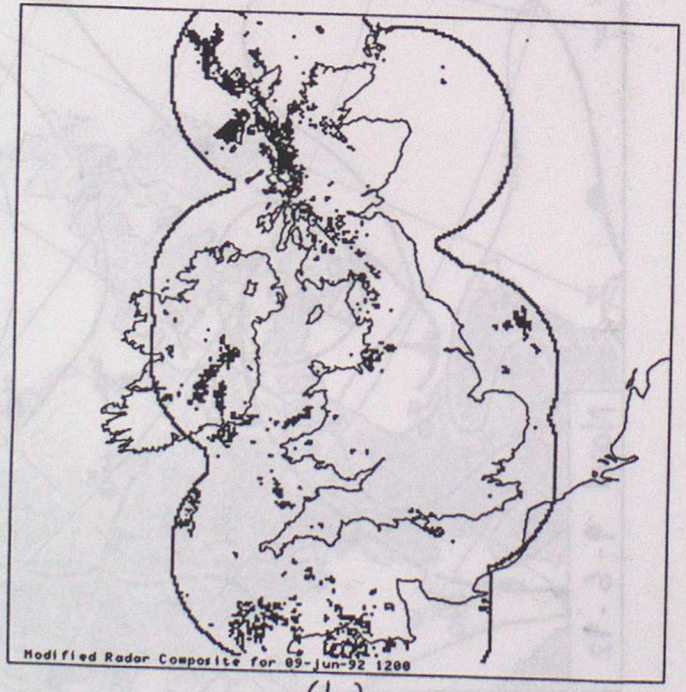


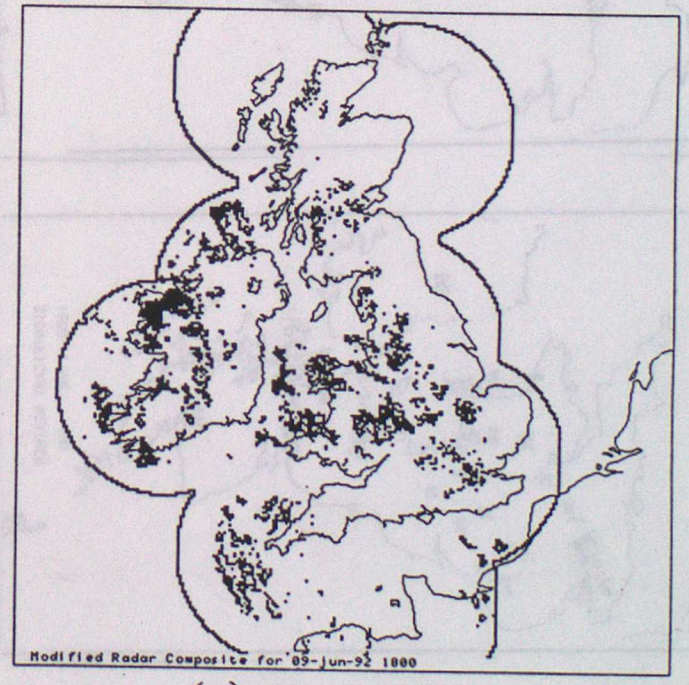
Figure 12(a) T+36 mean sea level pressure and rainfall forecast from from the old operational LAM
Figure 12 (b) and (c)
Modified Radar Composites for 12Z/18Z 09/06/92



(a)



(b)

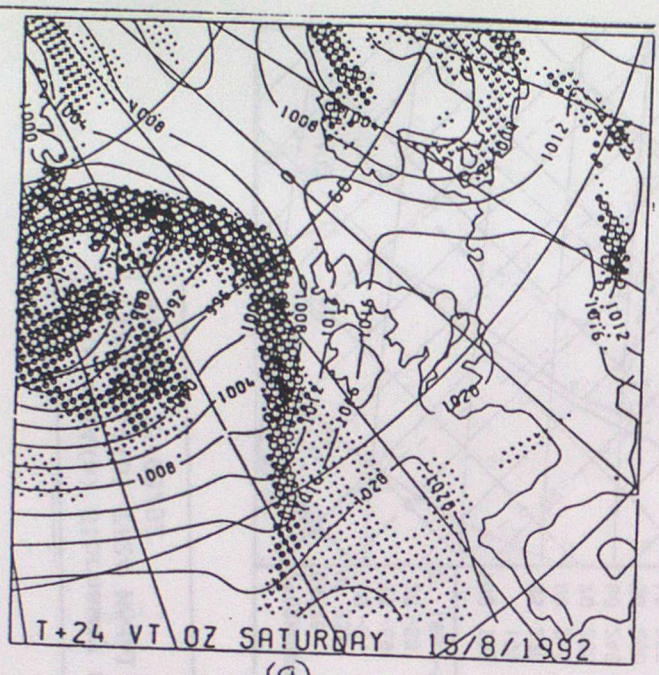


(c)

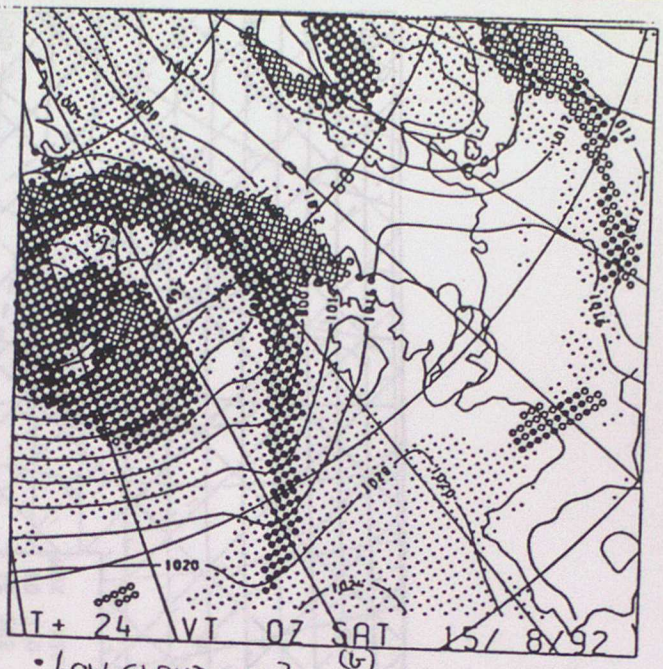
SNOW PROBABILITY AT MSL
TOTAL PPN RATE
PRESSURE AT MSL

DT 00Z FRIDAY 14/8/1992 LMAIN

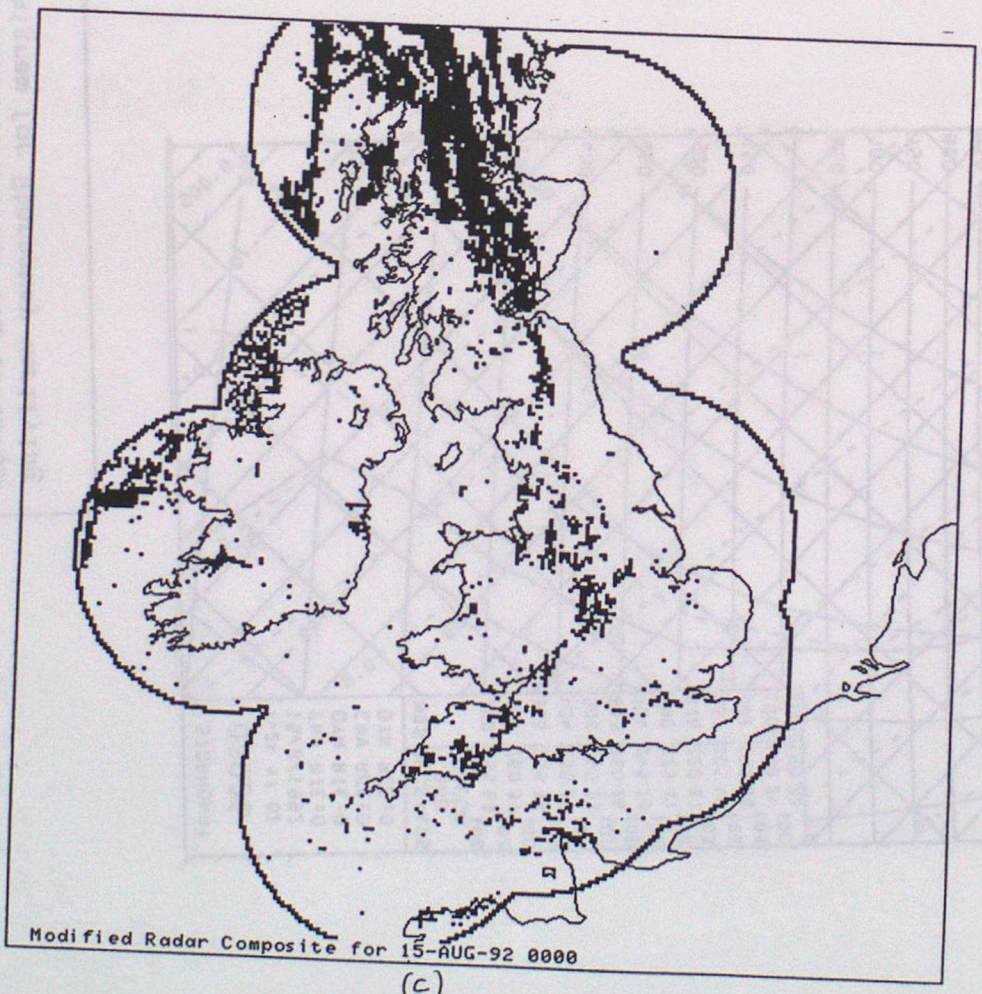
SNOW
CONVECTIVE
DYNAMIC



(a)
mslp + rainfall.



(b)
• Low cloud
o Medium cloud
} > 4 octas



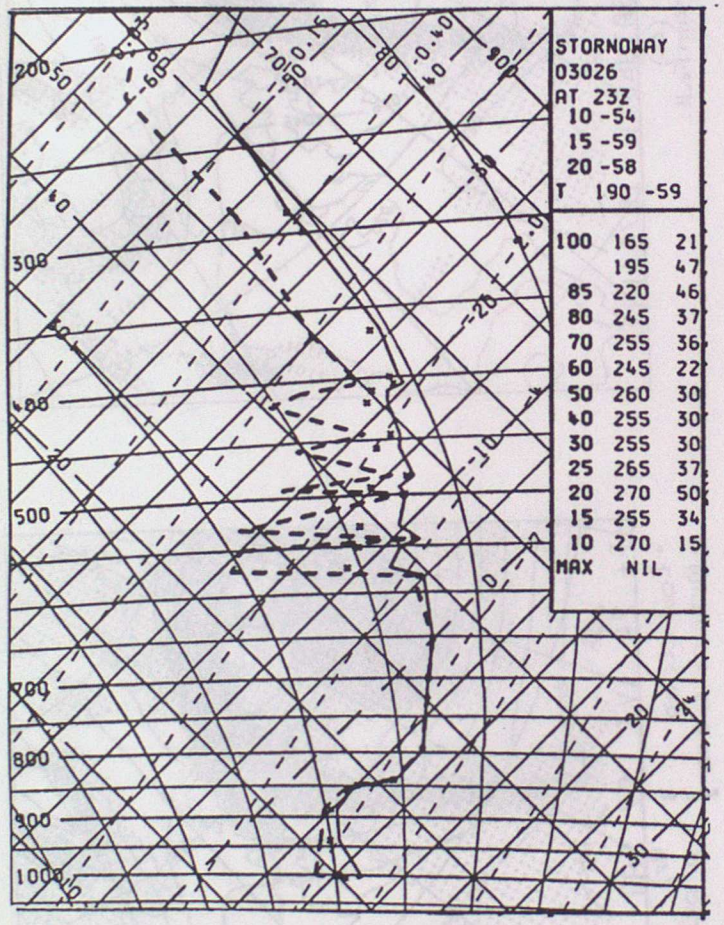
(c)

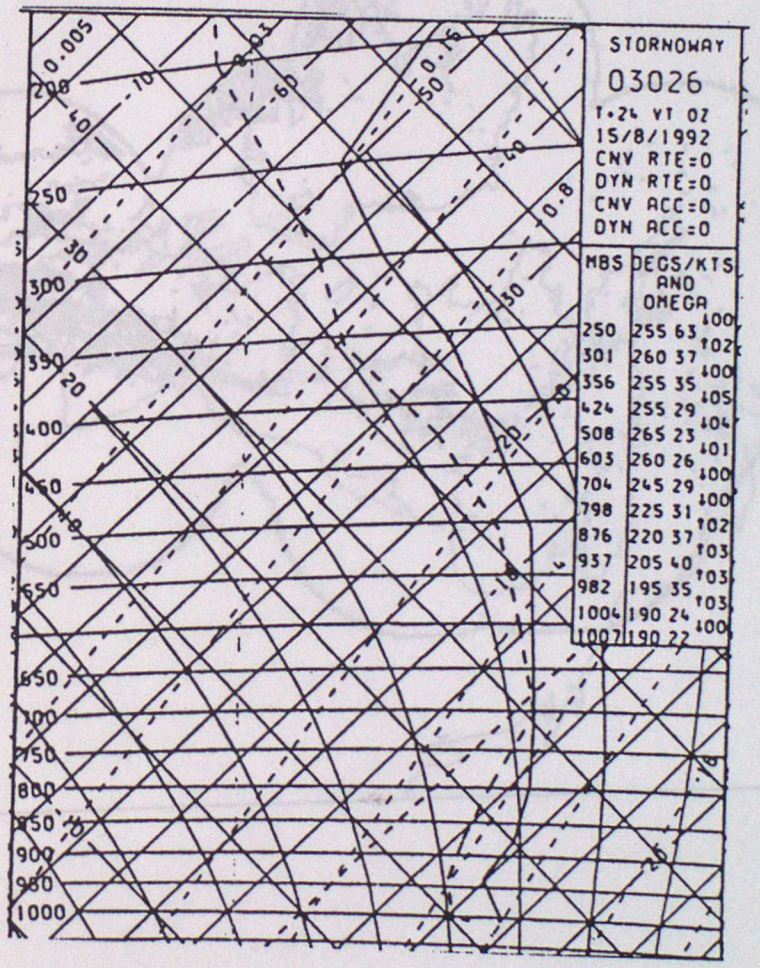
Figure 13a T+24 mean sea level pressure and rainfall forecast verifying at 00Z 15/08/92

Figure 13b T+24 forecast of low and medium cloud layers > 4 octas, verifying at 00Z 15/08/92

Figure 13c Radar composite for 00Z 15/08/92

Figure 14(a) Stornaway radiosonde ascent for 00Z 15/08/92
Figure 14(b) T+24 Model tephigram for Stornaway verifying at 00Z 15/08/92





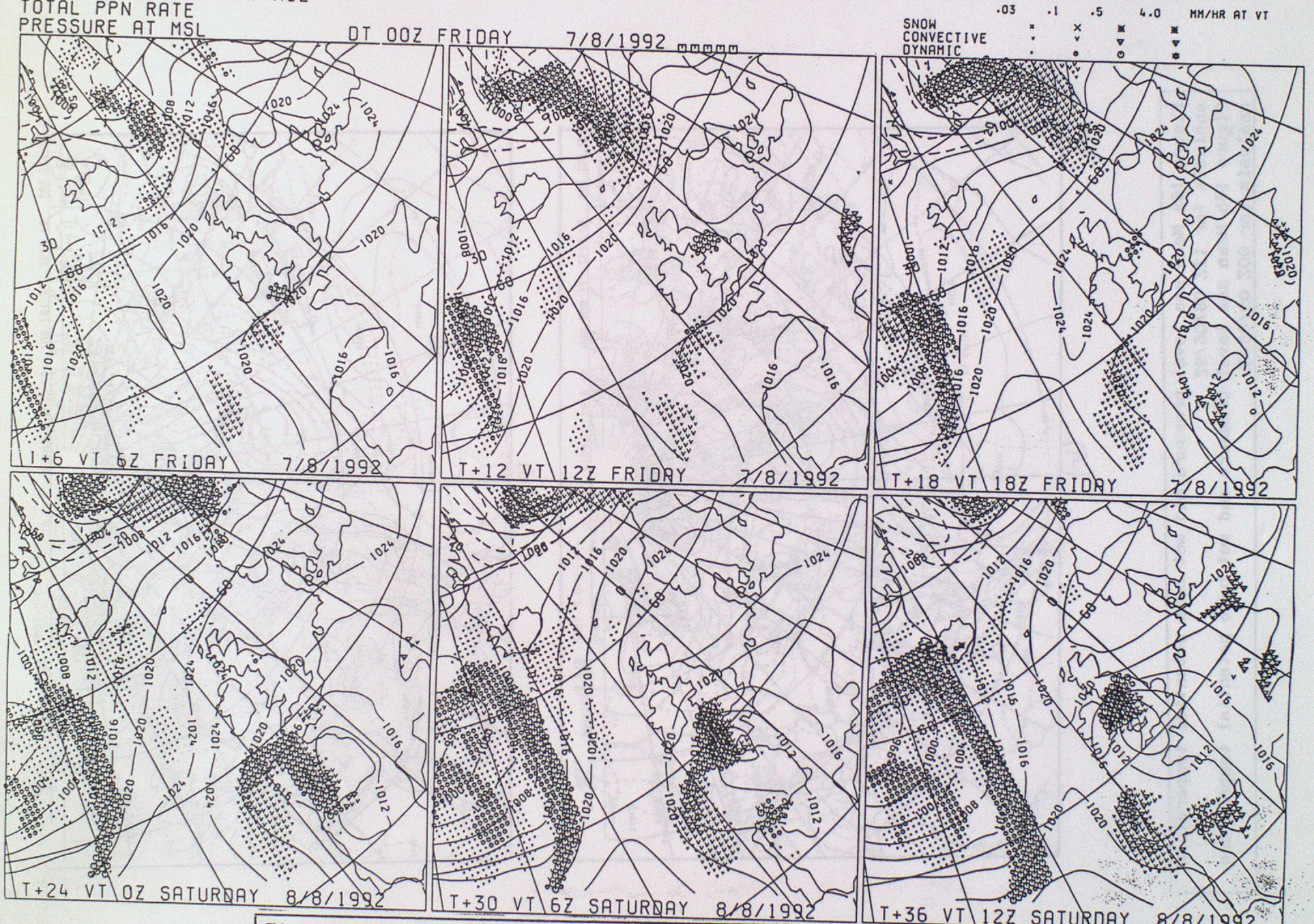
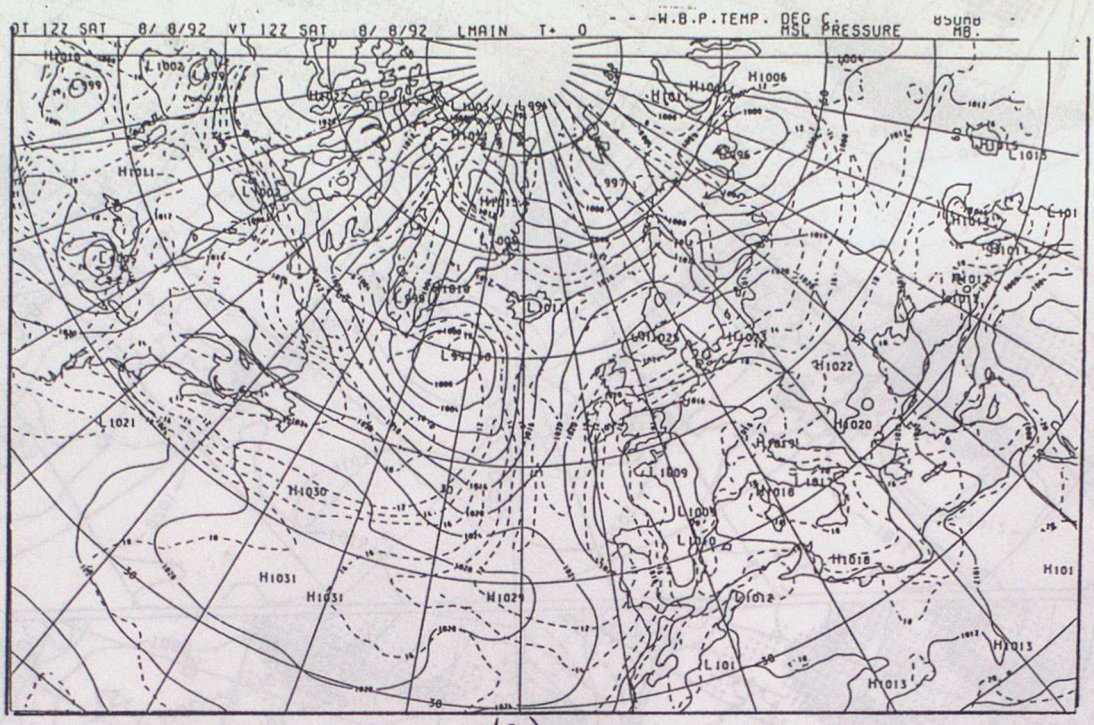
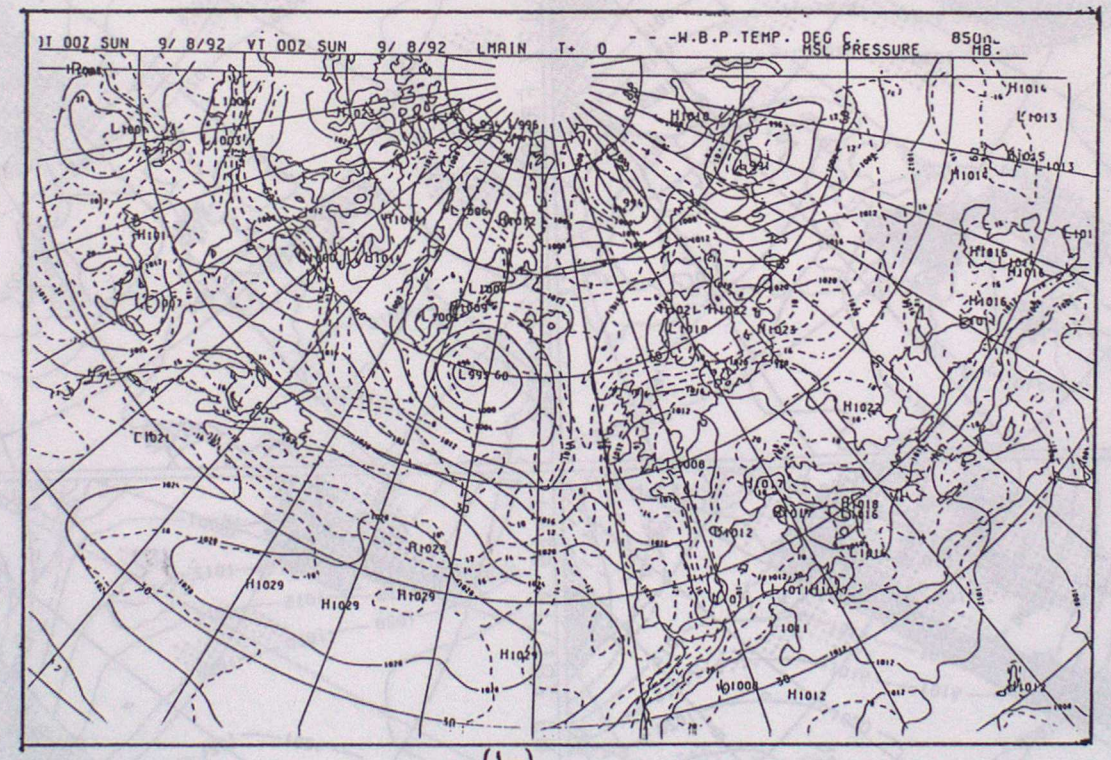


Figure 15 Mean sea level pressure and rainfall forecast from DT 00Z 07/08/92

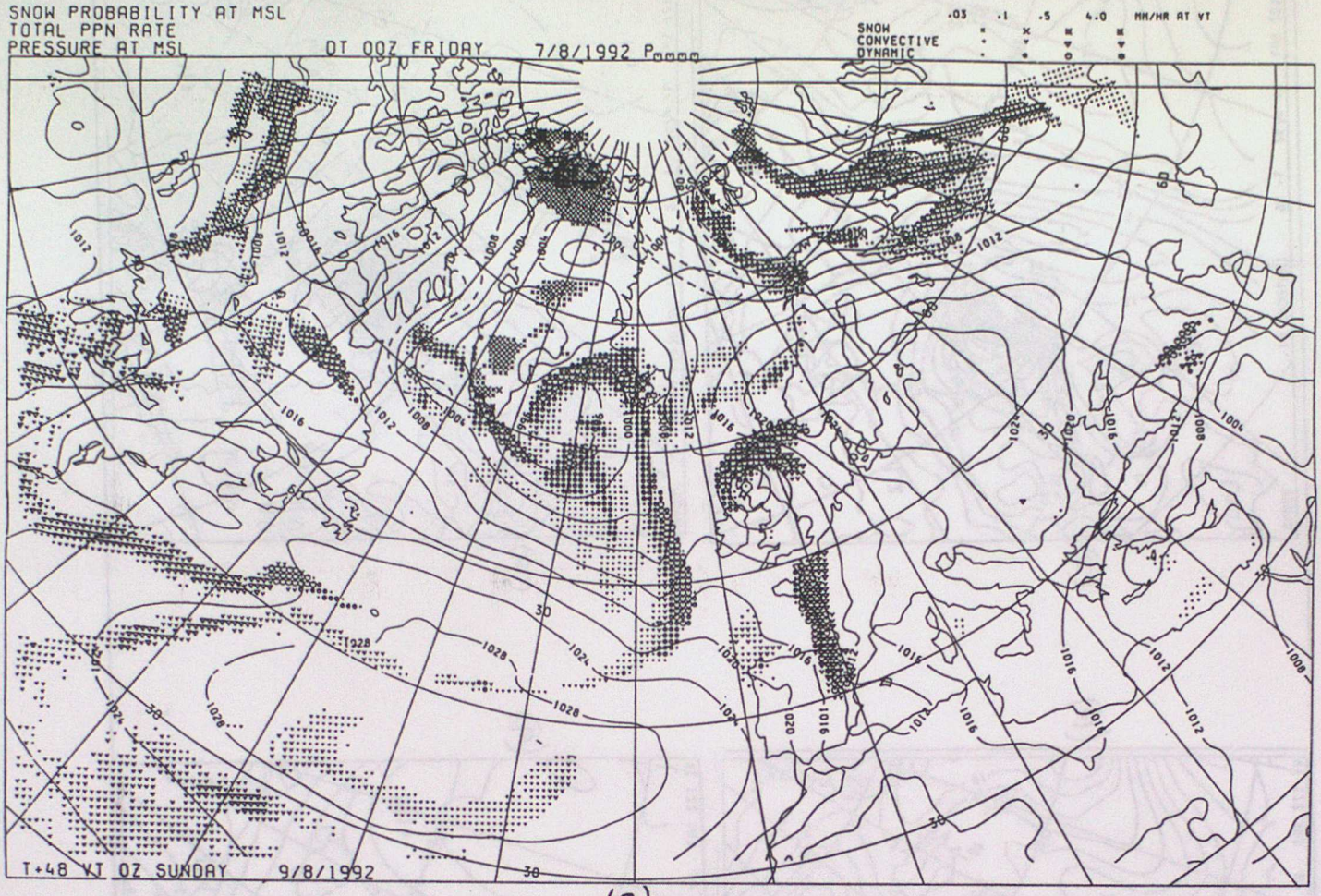


(a)



(b)

Figure 16a Mean sea level pressure and wet bulb potential temperature analysis for 12Z 08/08/92
Figure 16b Mean sea level pressure and wet bulb potential temperature analysis for 00Z 09/08/92



(a)

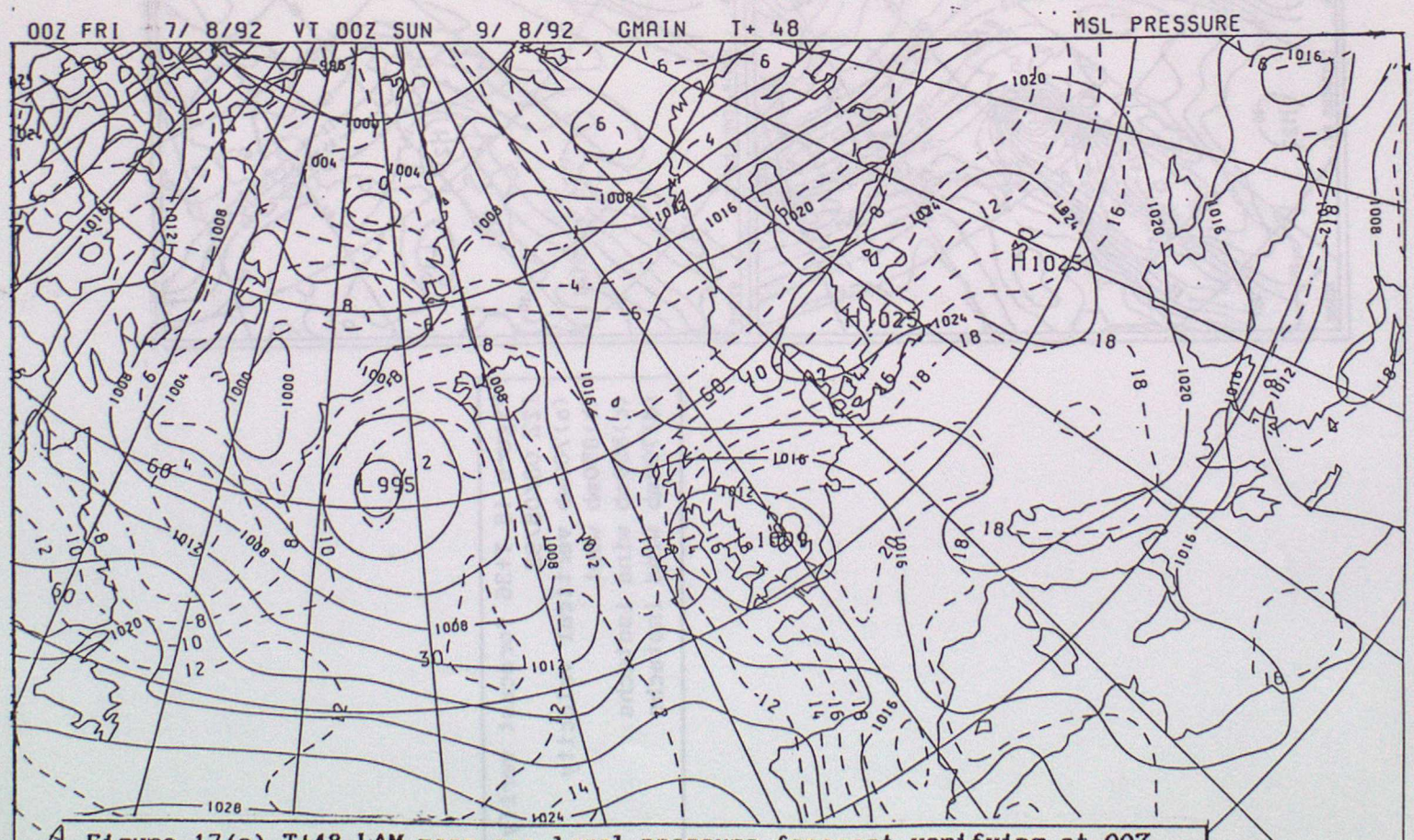


Figure 17(a) T+48 LAM mean sea level pressure forecast verifying at 00Z 09/08/92

Figure 17(b) T+48 Global mean sea level pressure forecast verifying at 00Z 09/08/92

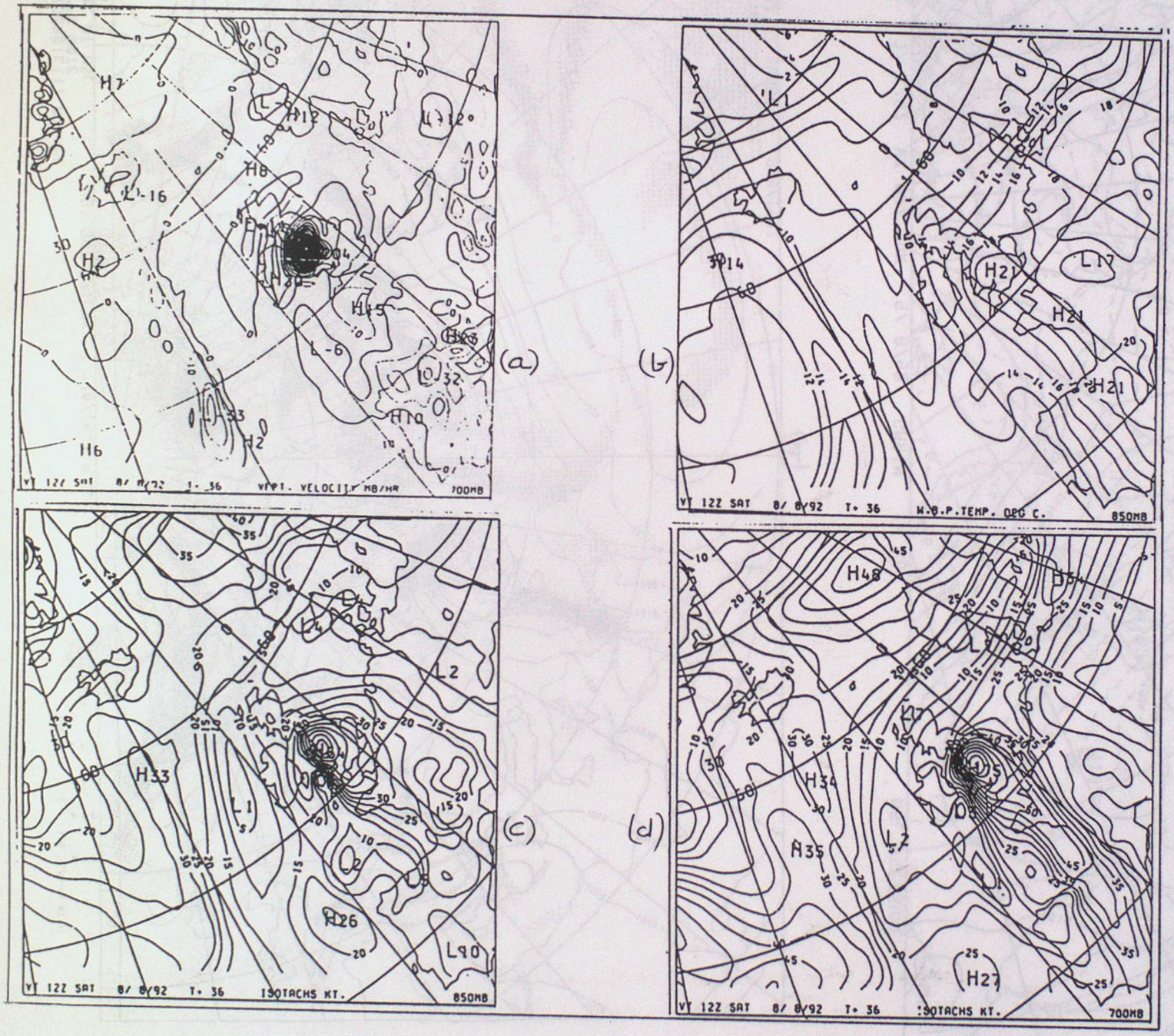
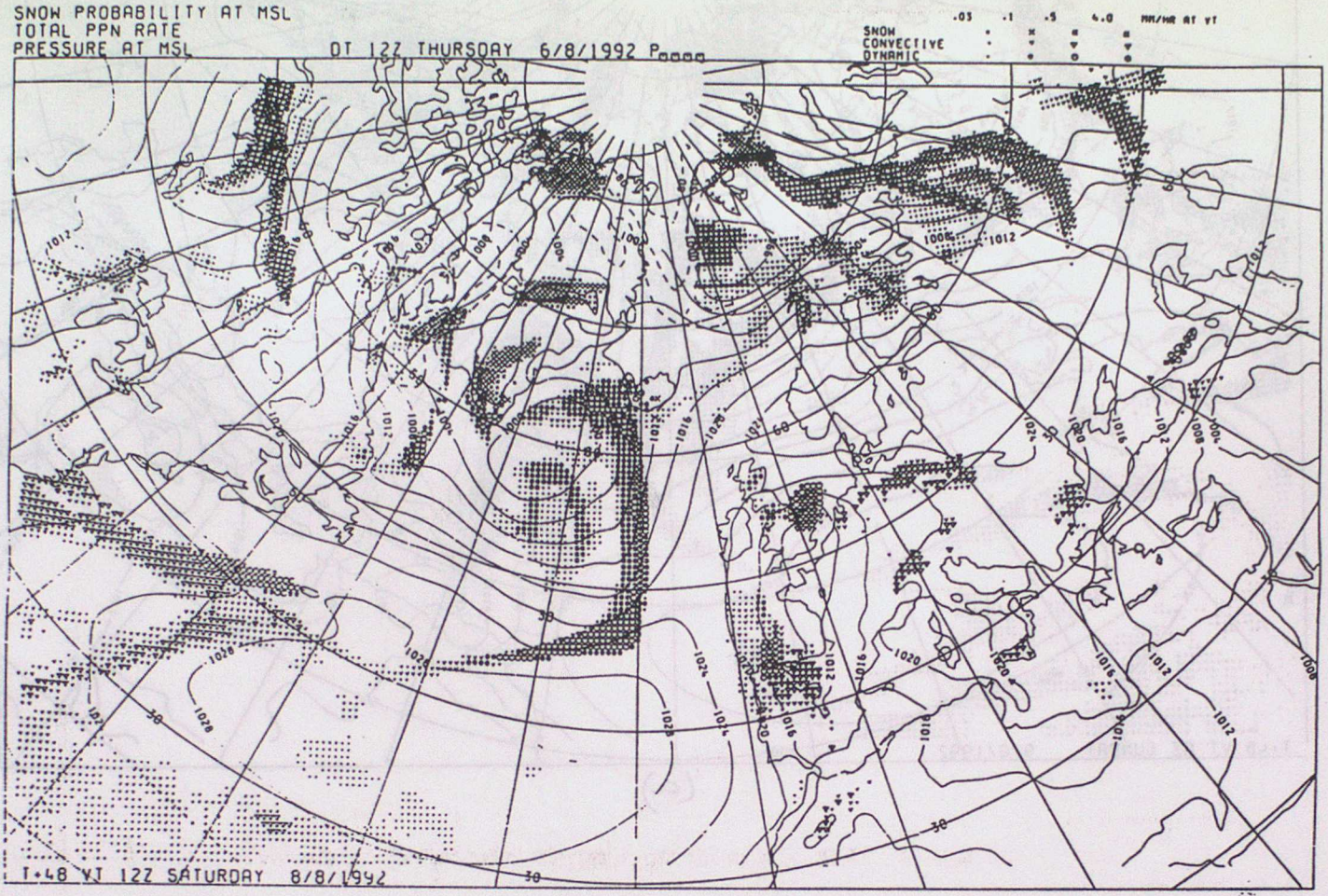


Figure 18 T+36 forecast verifying 12Z 08/08/92
(a)700mb vertical velocity
(b)850mb wbpt
(c)850mb wind isotachs
(d)700mb wind isotachs



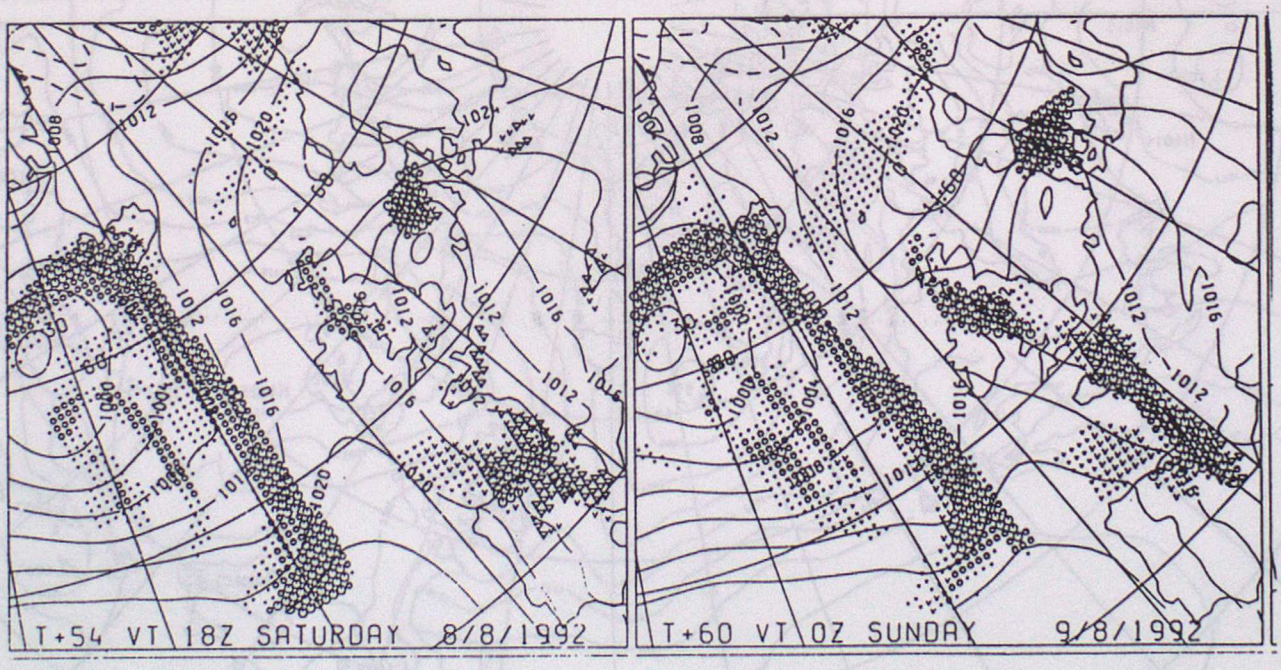
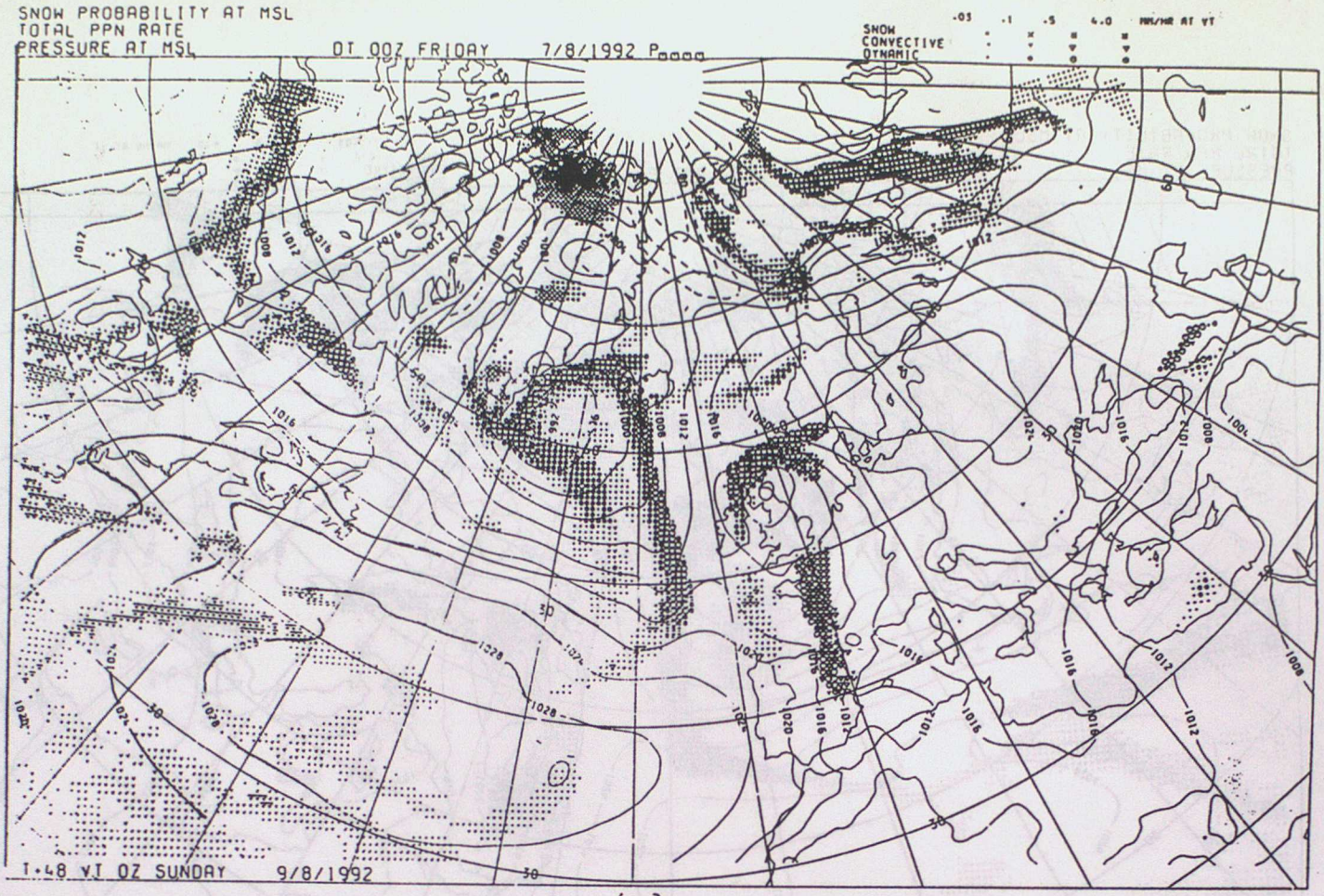
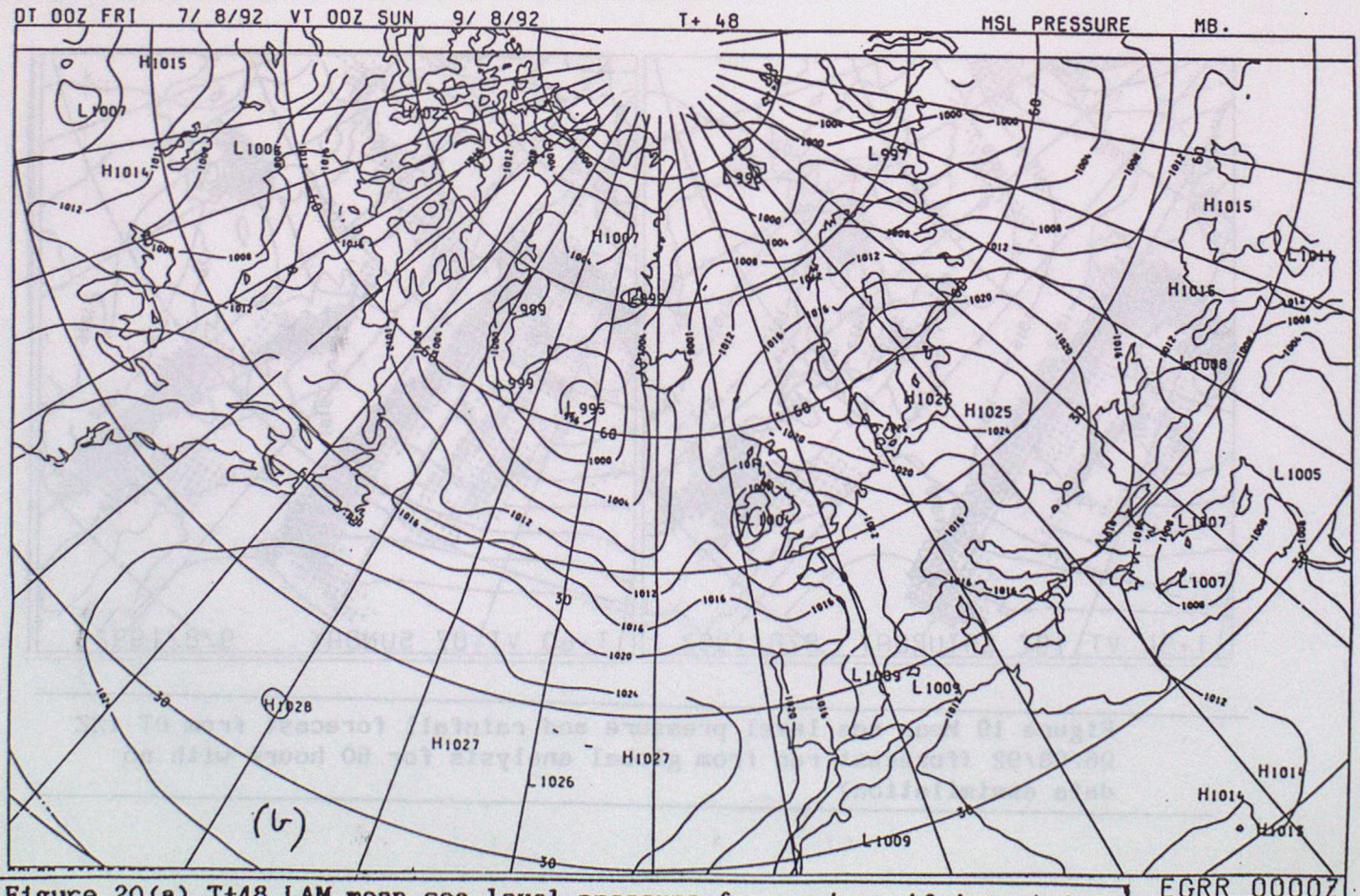


Figure 19 Mean sea level pressure and rainfall forecast from DT 12Z 06/08/92 (forecast run from global analysis for 60 hours with no data assimilation)



(a)



(b)

Figure 20(a) T+48 LAM mean sea level pressure forecast verifying at 00Z 09/08/92 (forecast run from global analysis DT00Z 07/08/92)
Figure 20(b) T+48 LAM mean sea level pressure forecast verifying at 00Z 09/08/92 (no physics run)

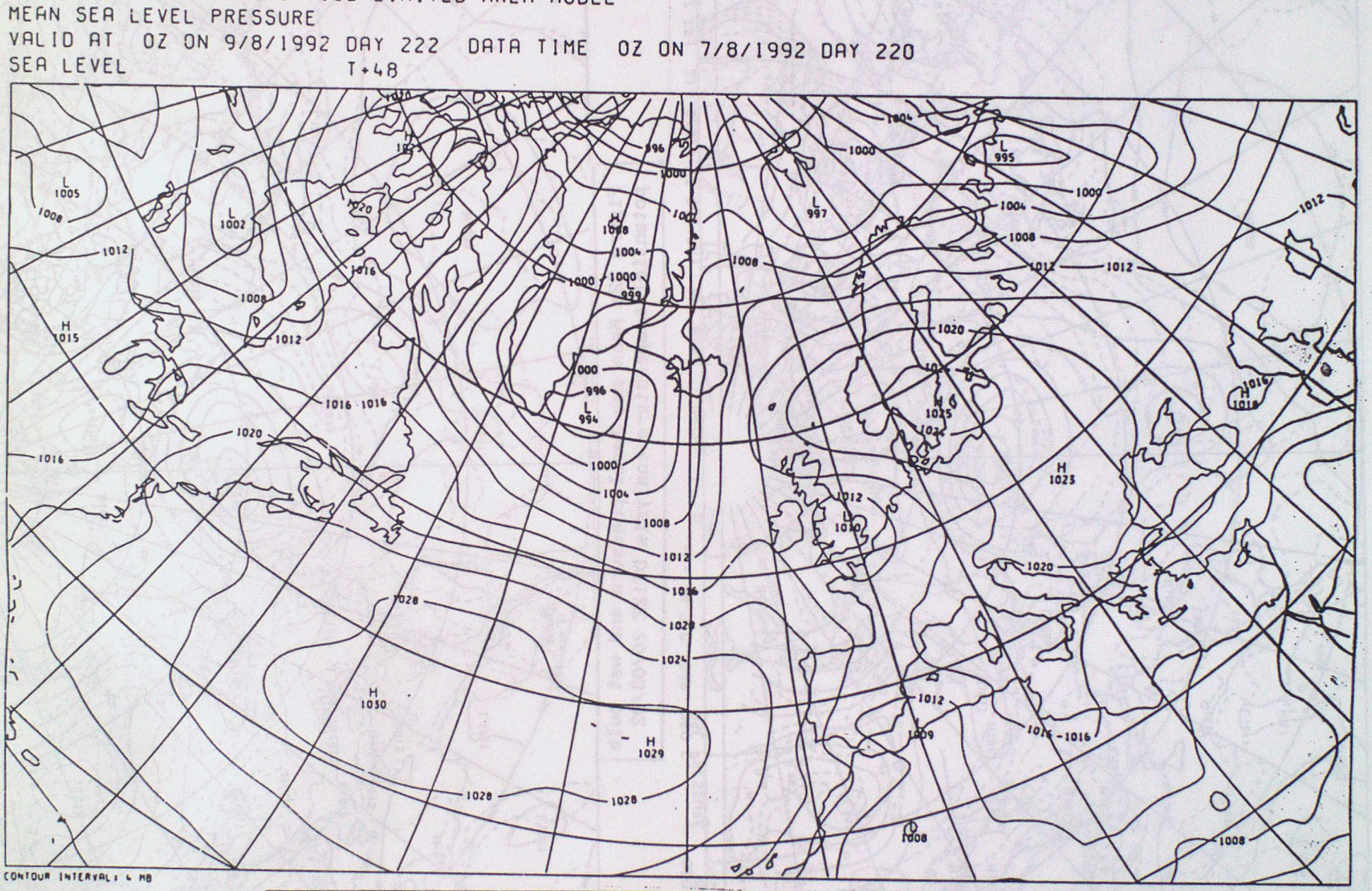


Figure 21(a) T+48 LAM mean sea level pressure forecast verifying at 00Z 09/08/92 (forecast run with global resolution)

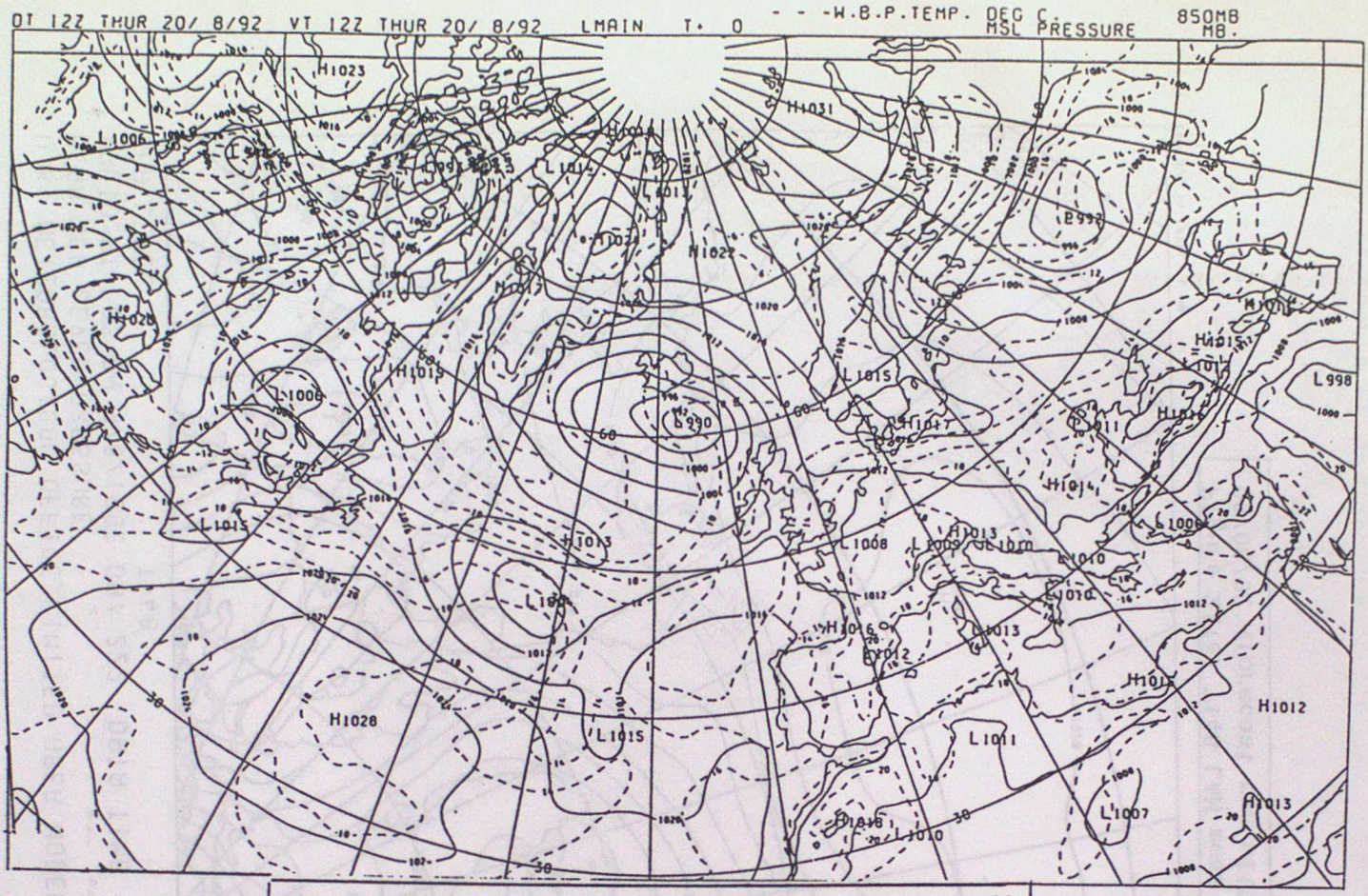


Figure 22a Mean sea level pressure and wet bulb potential temperature analysis DT12Z 20/08/92

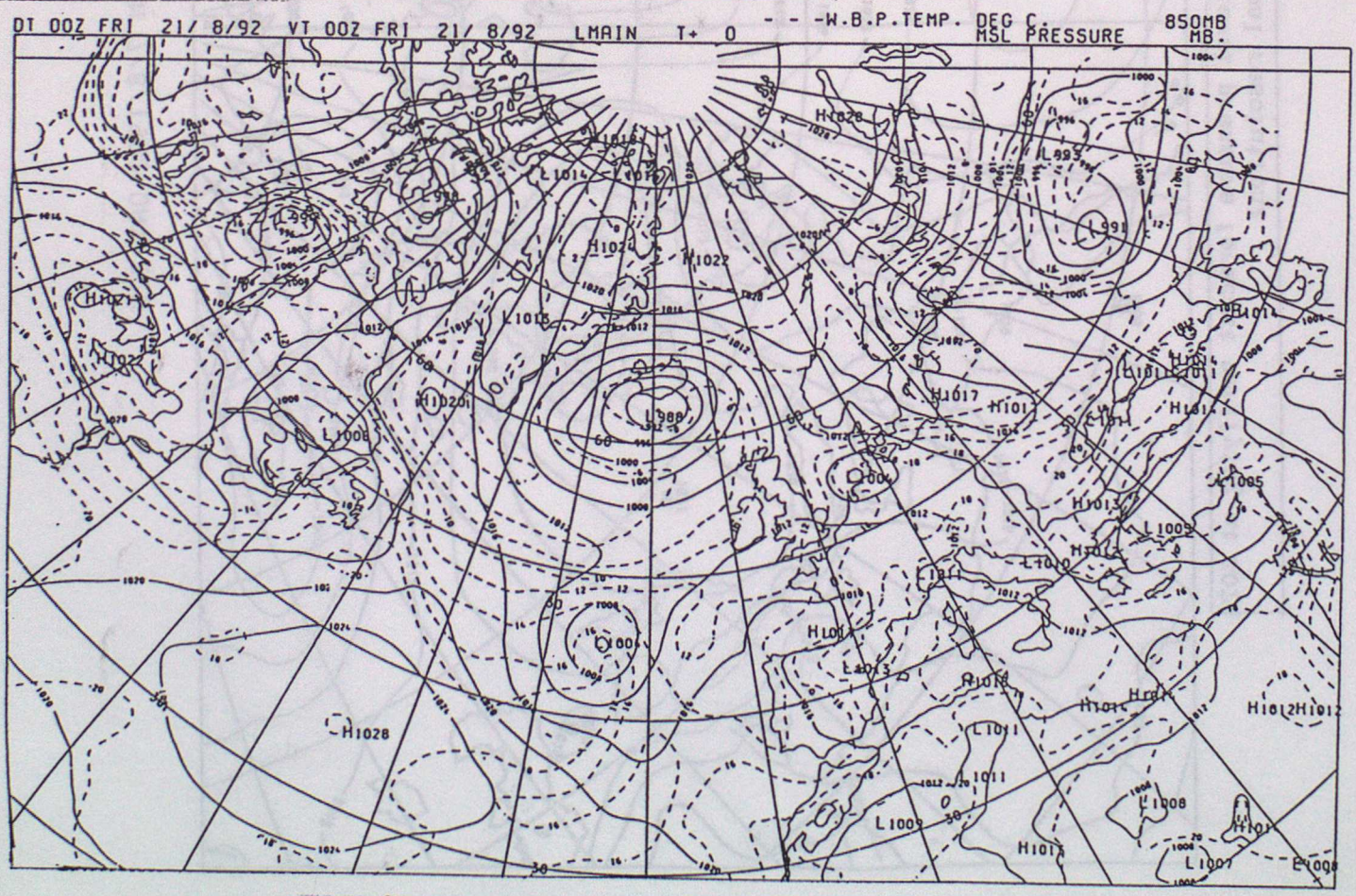


Figure 22b Mean sea level pressure and wet bulb potential temperature analysis DT00Z 21/08/92

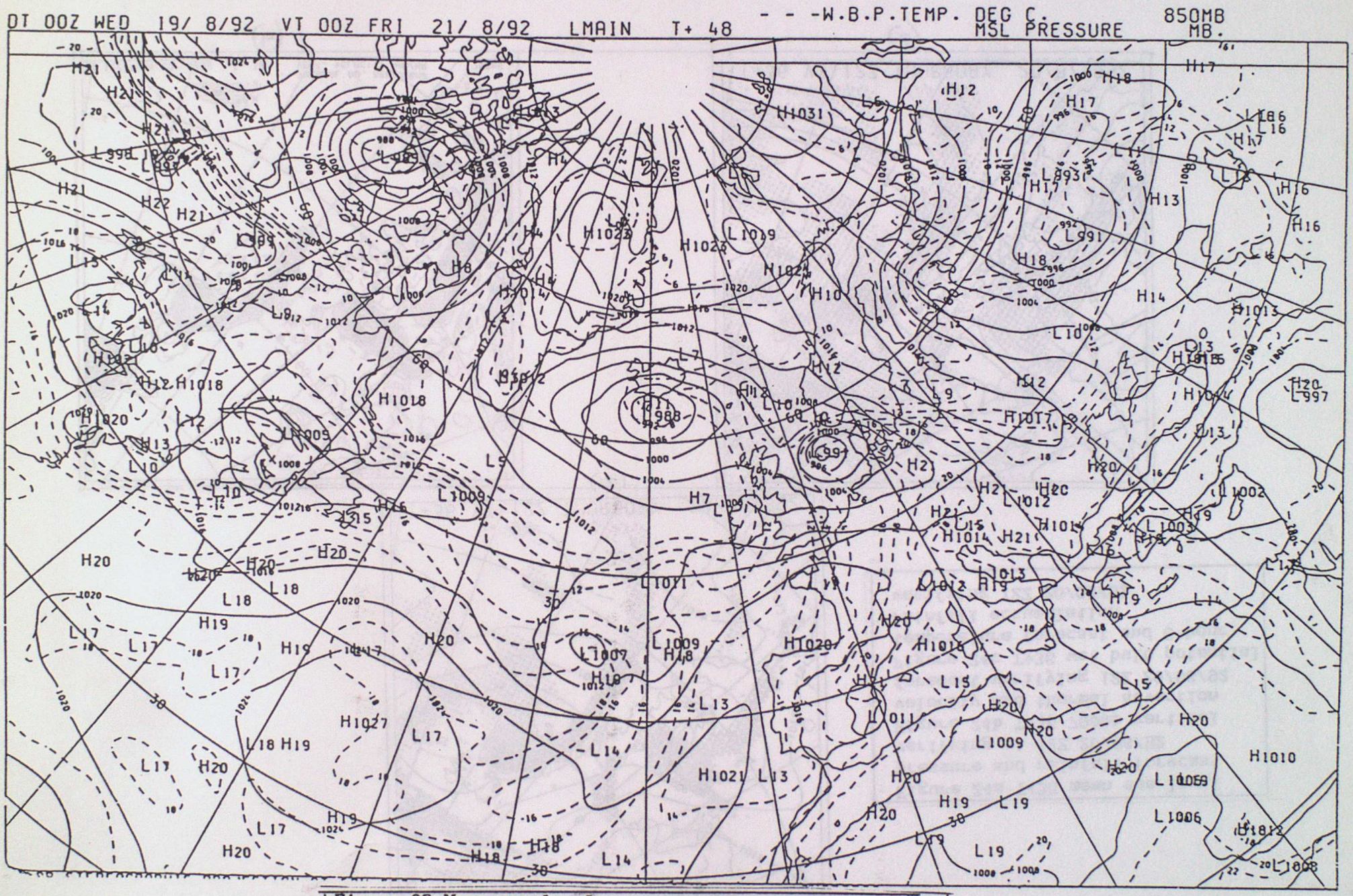
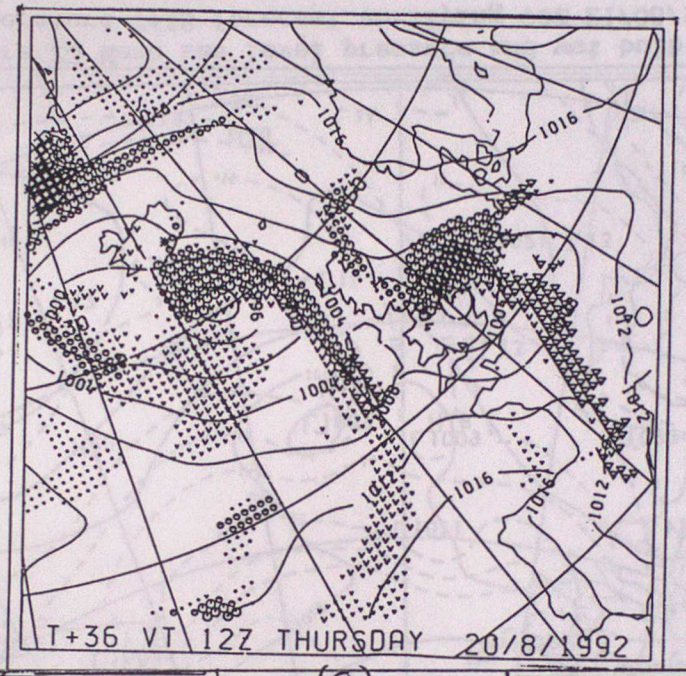
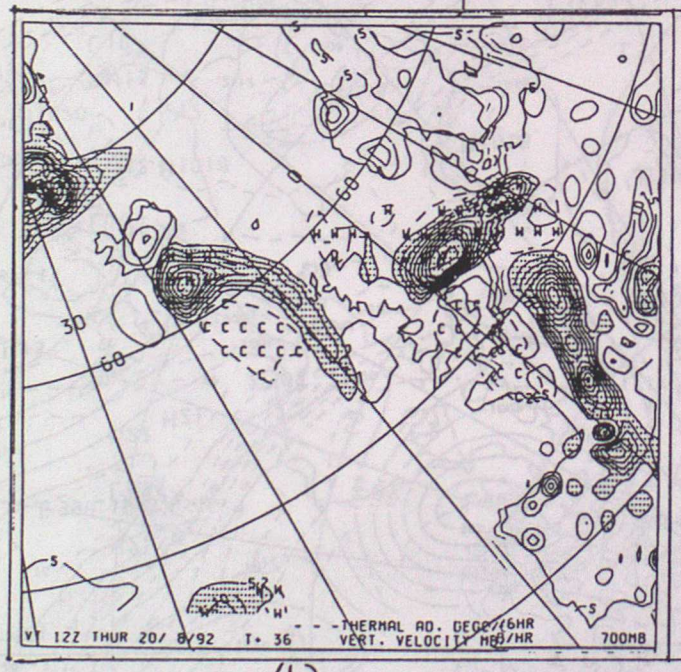


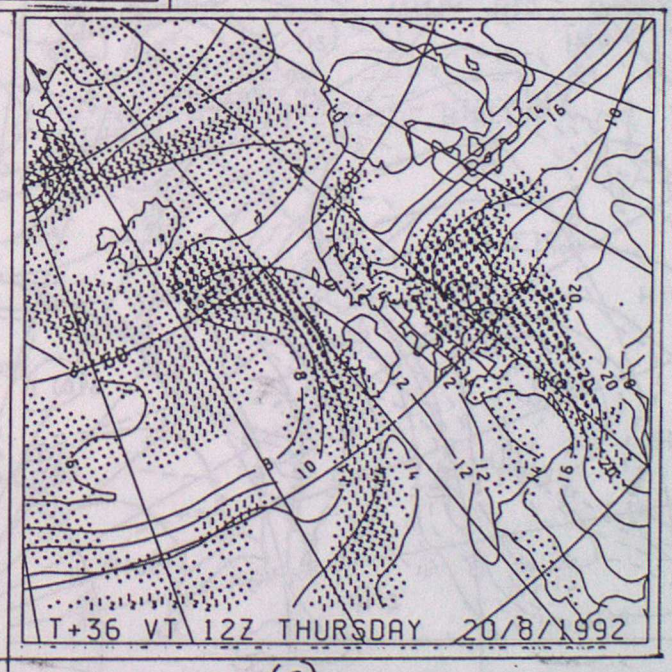
Figure 23 Mean sea level pressure and wet bulb potential temperature T+48 forecast verifying 00Z 21/08/92



(a)



(b)



(c)

Figure 24a T+36 mean sea level pressure and rainfall forecast verifying at 12Z 20/08/92
Figure 24b T+36 700mb vertical velocity and thermal advection forecast verifying 12Z 20/08/92
Figure 24c T+36 wet bulb potential temperature forecast and 6-hour rainfall accumulation verifying 12Z 20/08/92

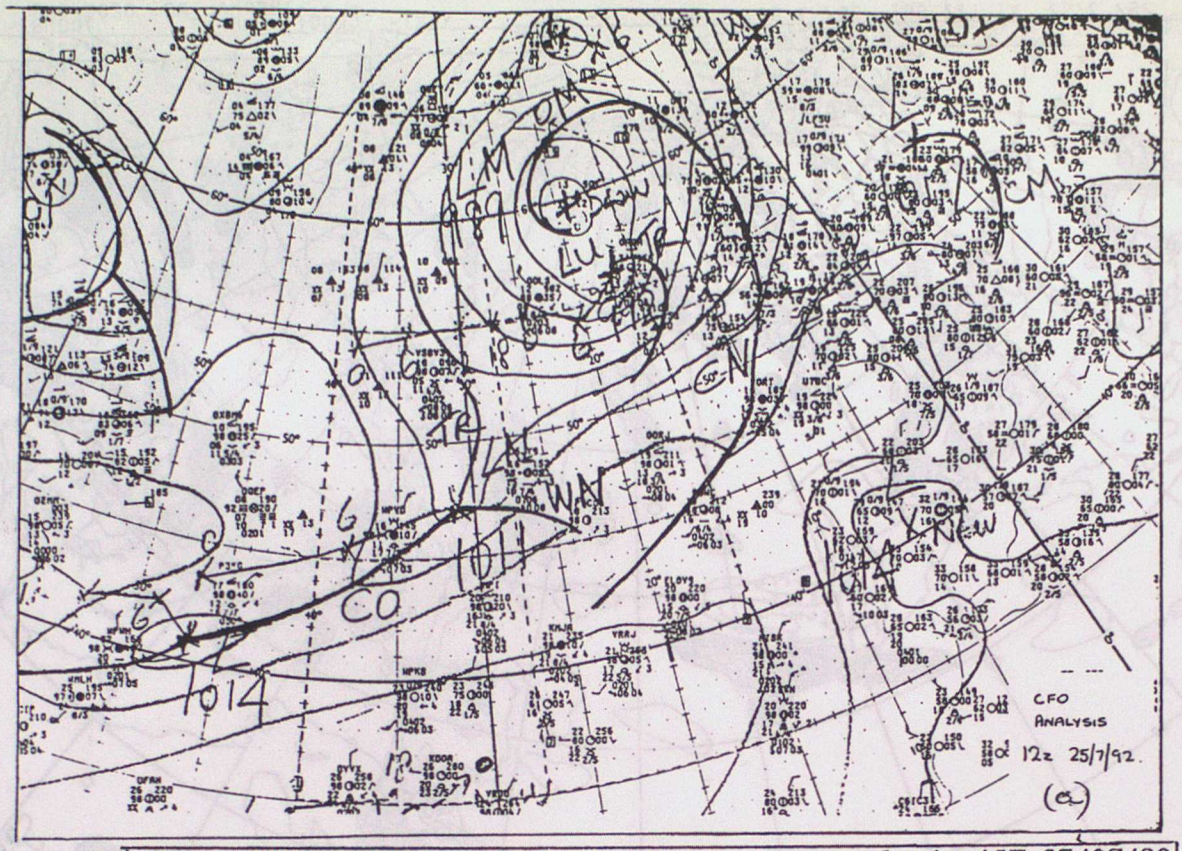


Figure 25a C.F.O. mean sea level pressure analysis 12Z 25/07/92

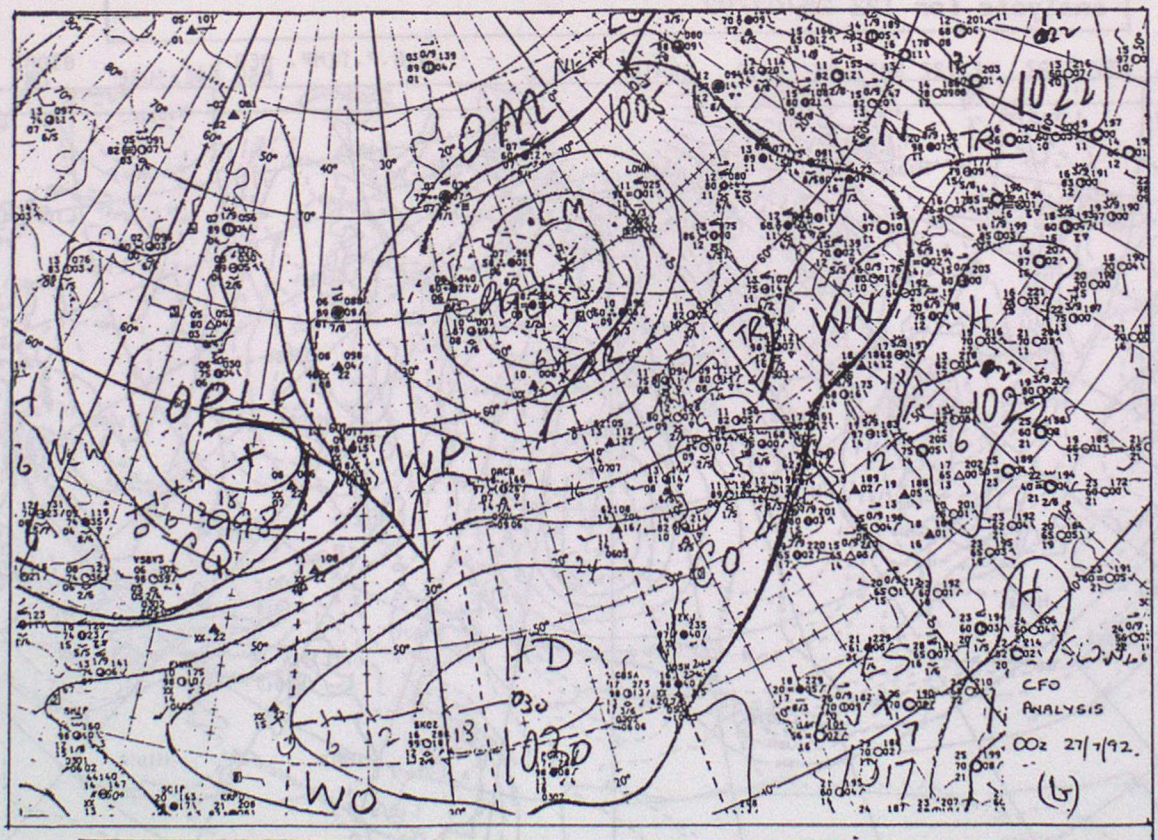


Figure 25b C.F.O. mean sea level pressure analysis 00Z 27/07/92

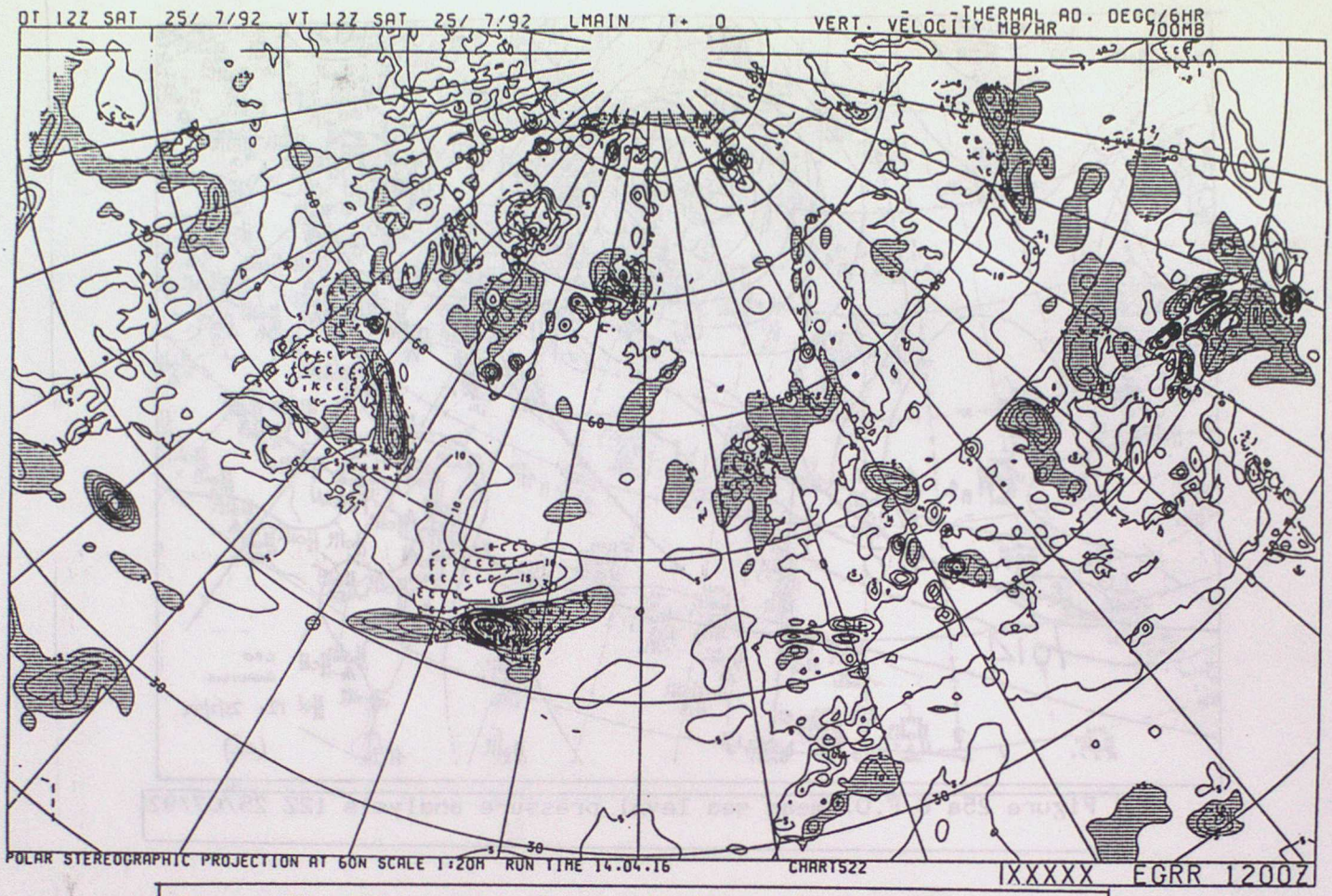


Figure 26a 700mb vertical velocity/thermal advection analysis for 12Z 25/07/92

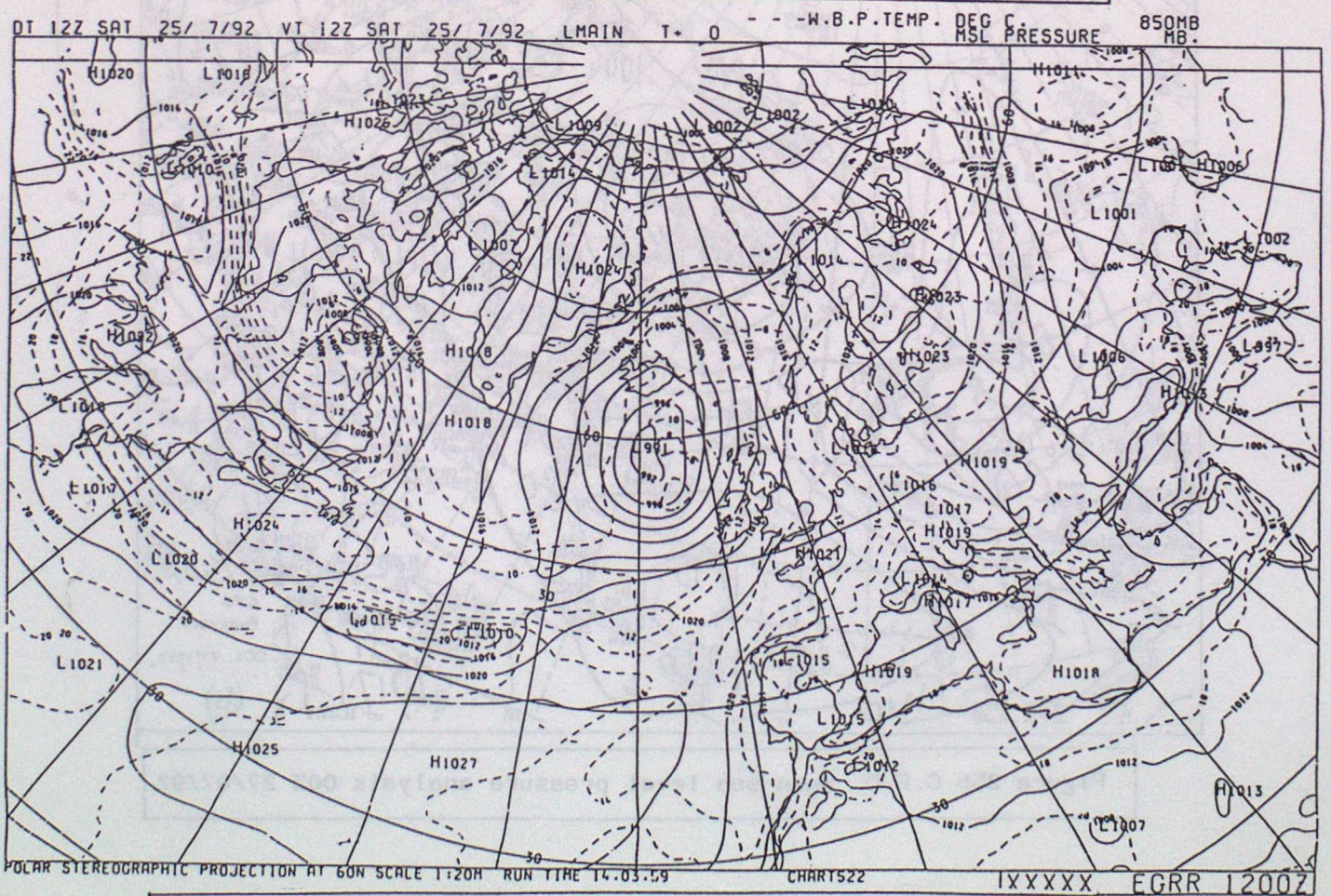


Figure 26b mean sea level pressure/850mb wet bulb potential temperature analysis for 12Z 25/07/92

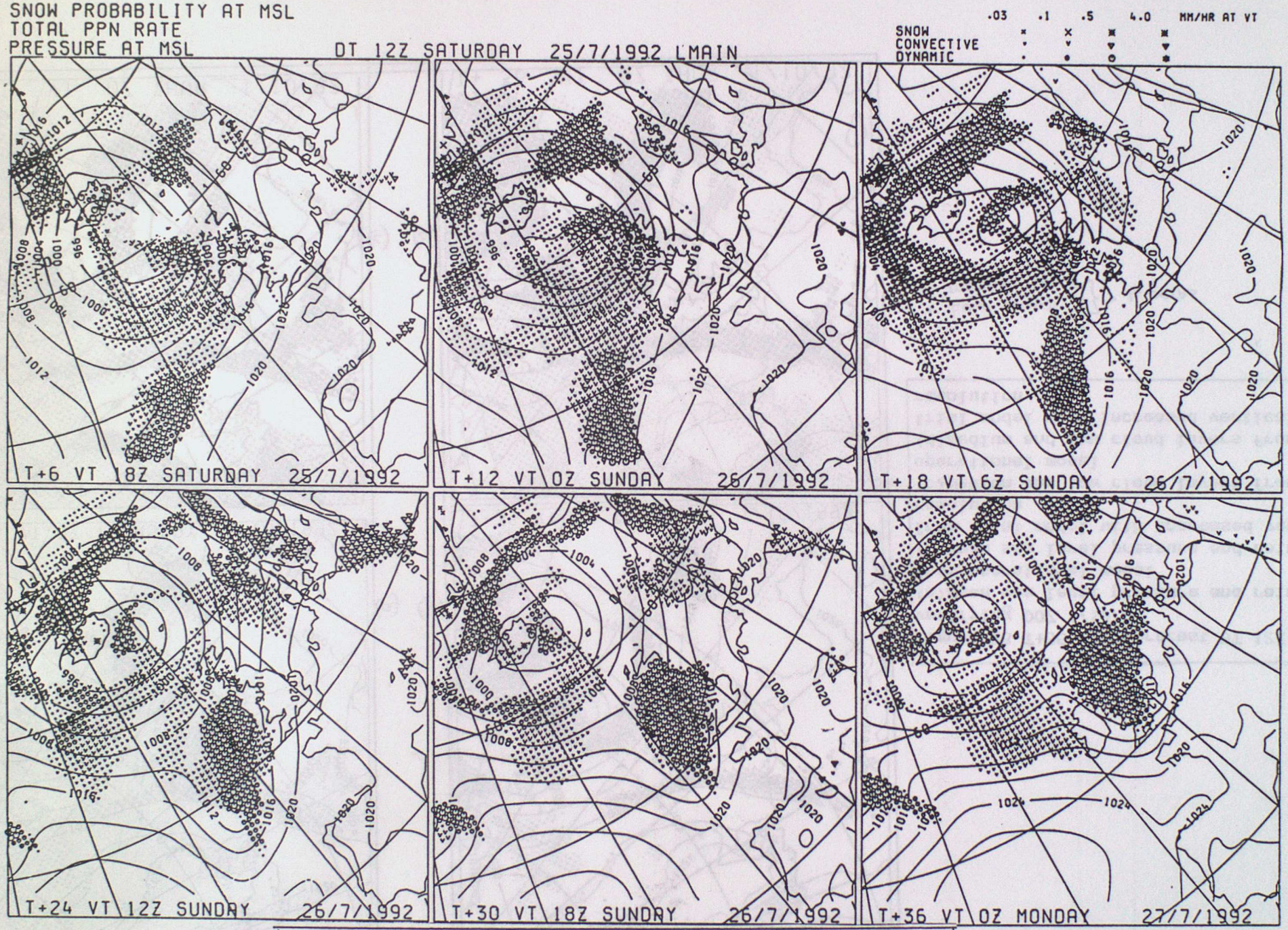


Figure 27 LAM forecast mean sea level pressure and rainfall from DT 12Z 25/07/92

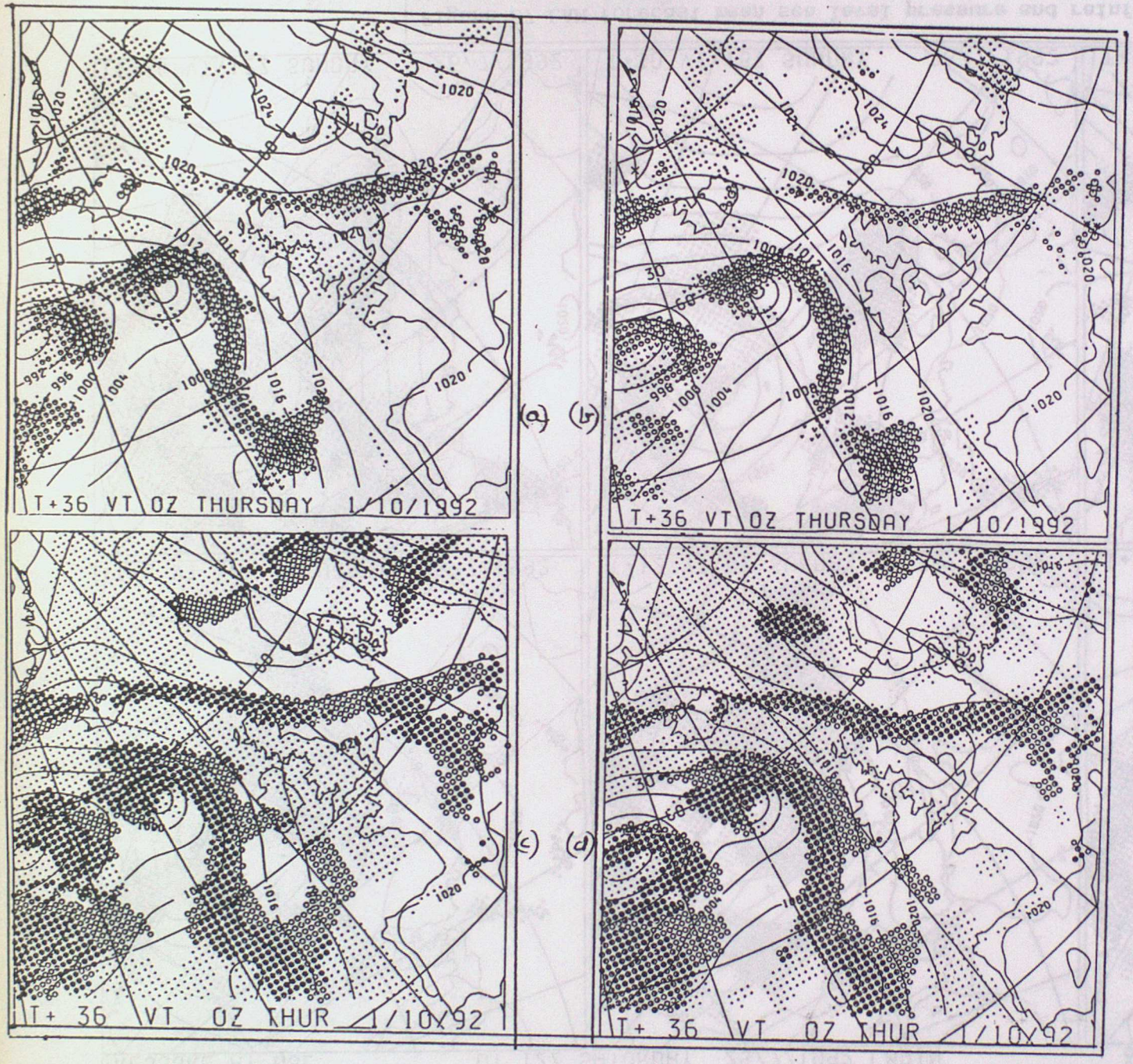
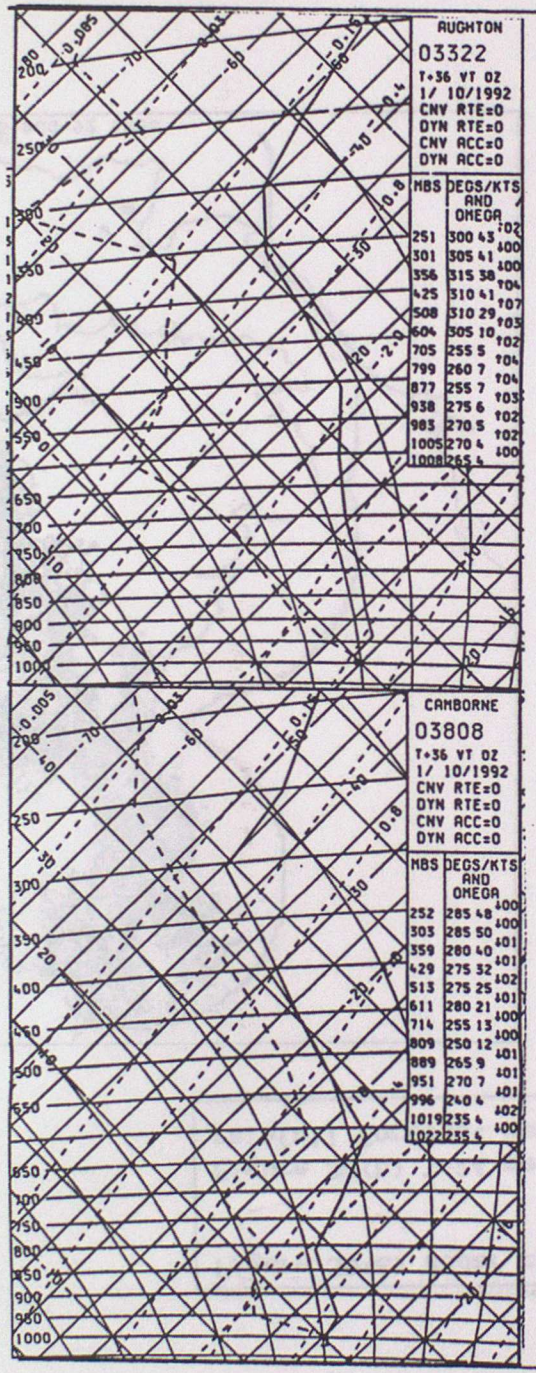


Figure 28 T+36 LAM forecast DT 12Z 29/09/92 verifying 00Z 1/10/92
(a)mean sea level pressure and rainfall from operational model
(b)mean sea level pressure and rainfall from trial model with increased vertical resolution
(c)medium and low cloud layers from operational model
(d)medium and low cloud layers from trial model with increased vertical resolution

• LOW CLOUD
o MEDIUM CLOUD
} > 4 OCTAS

Figure 29(a) T+36 forecast model tephigrams from operational LAM
Figure 29(b) T+36 forecast model tephigramsfrom trial model with increased vertical resolution [30 LEVELS]

(a)



(b)

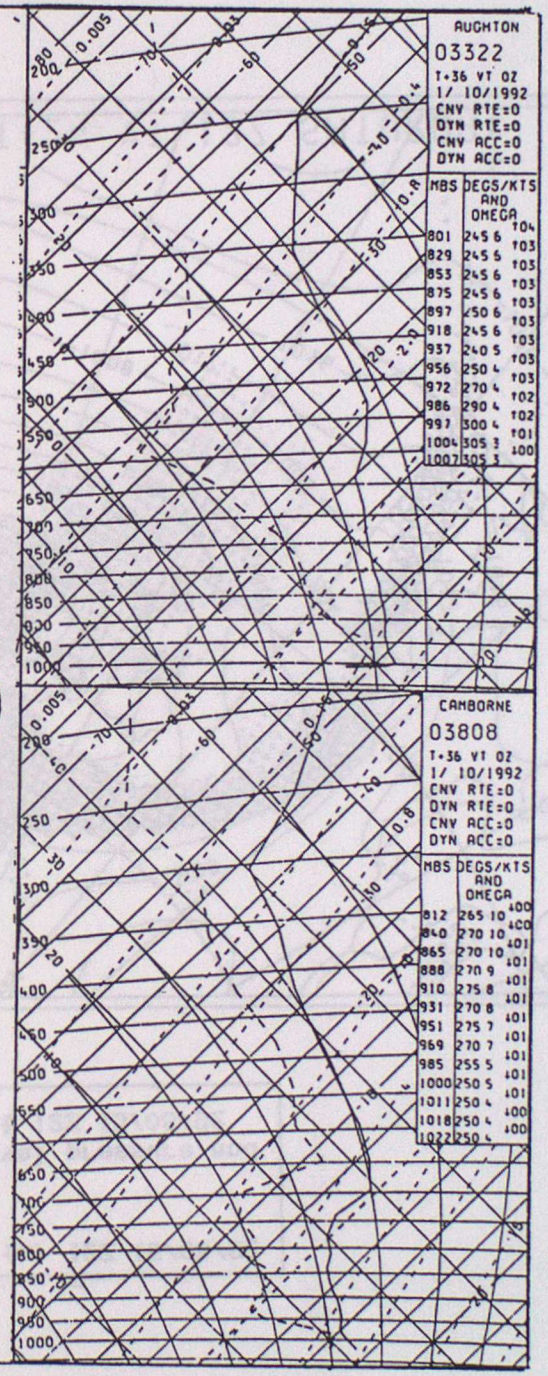
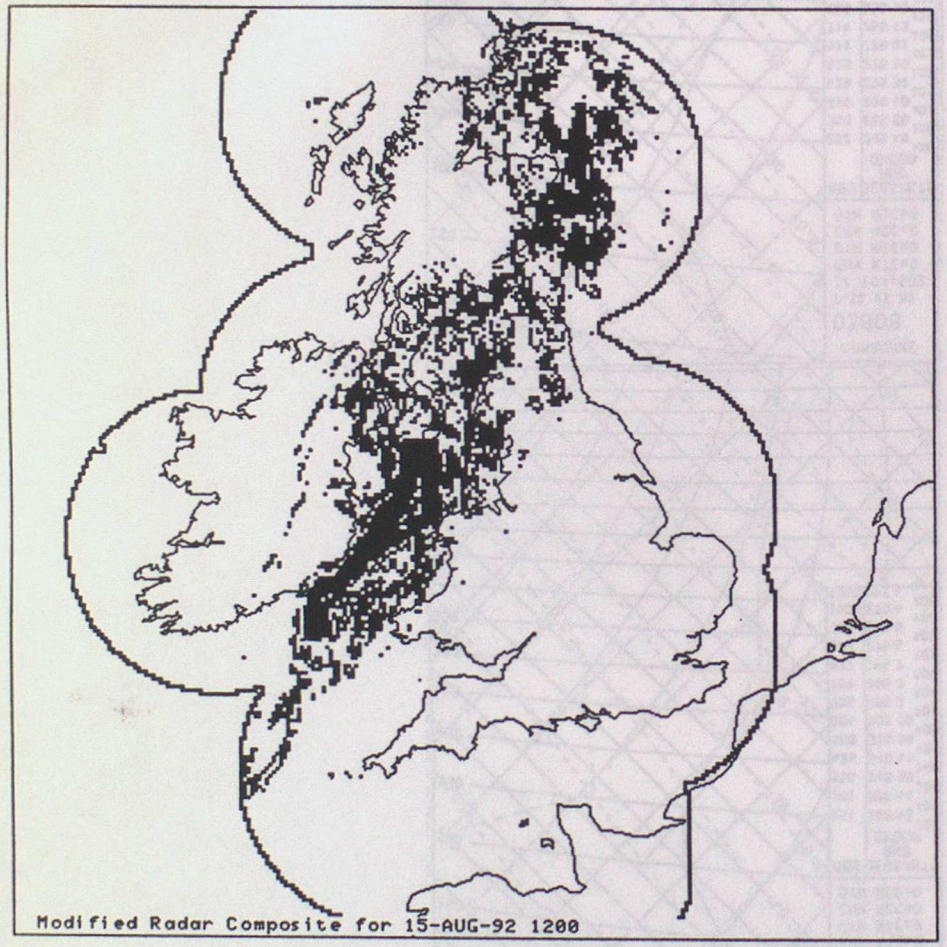
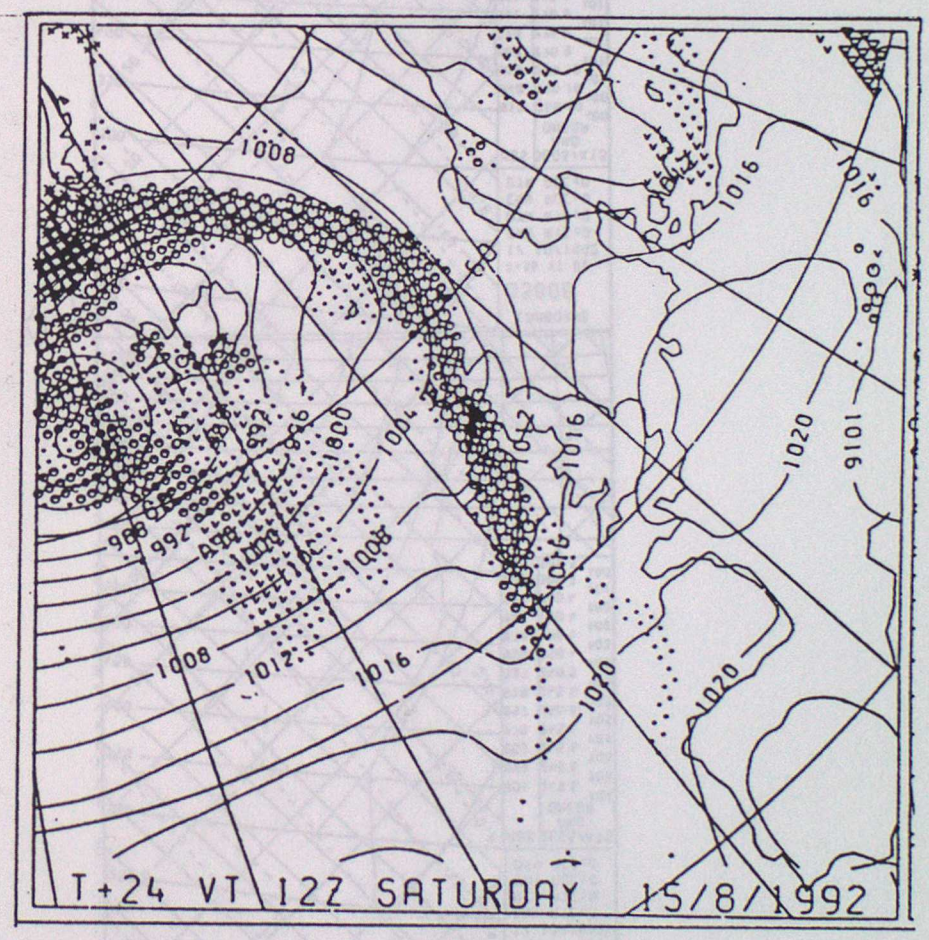


Figure 30(a) Radar composite for 12Z 15/08/92

Figure 30(b) T+24 mean sea level pressure and rainfall forecast verifying at 12Z 15/08/92





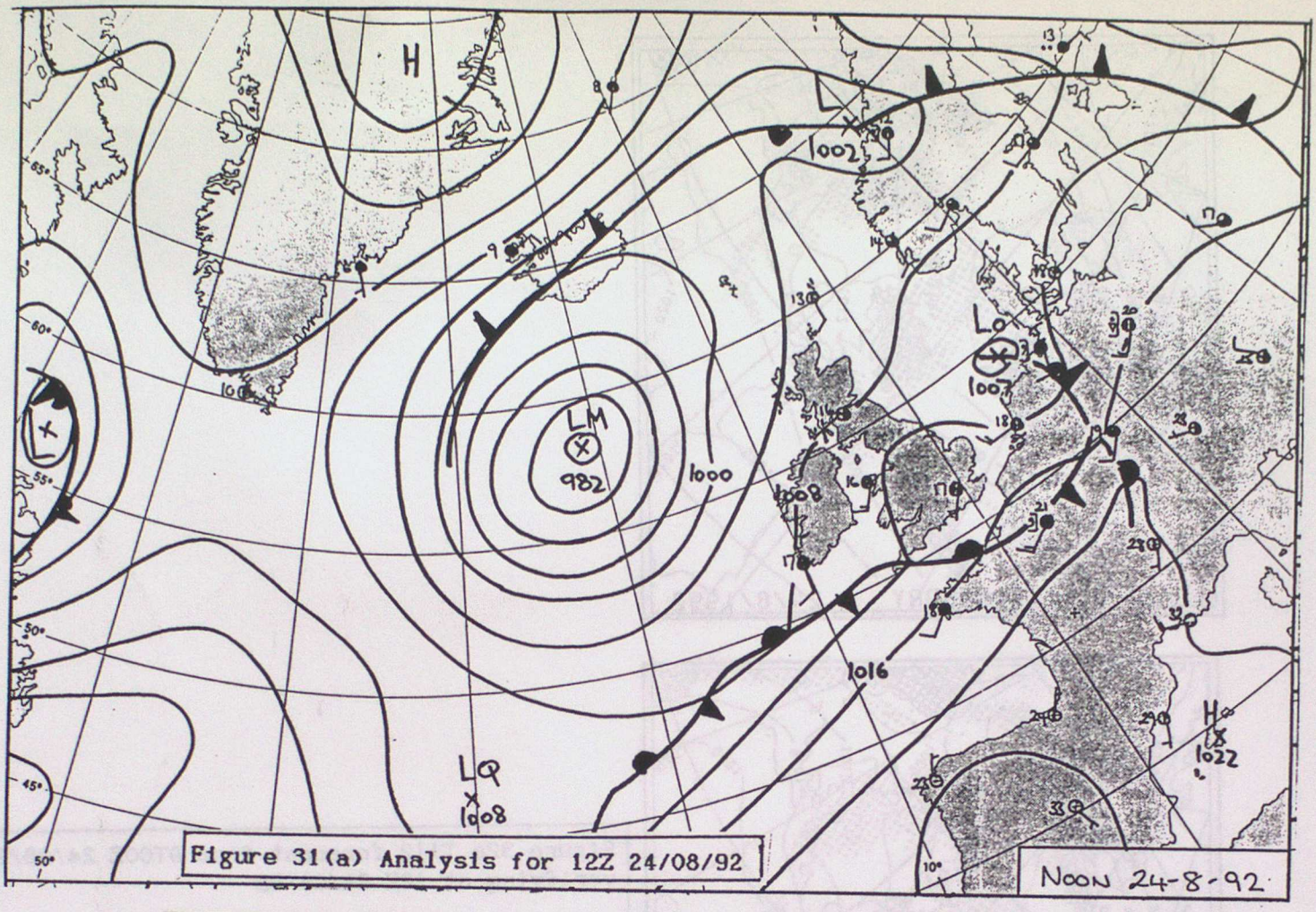
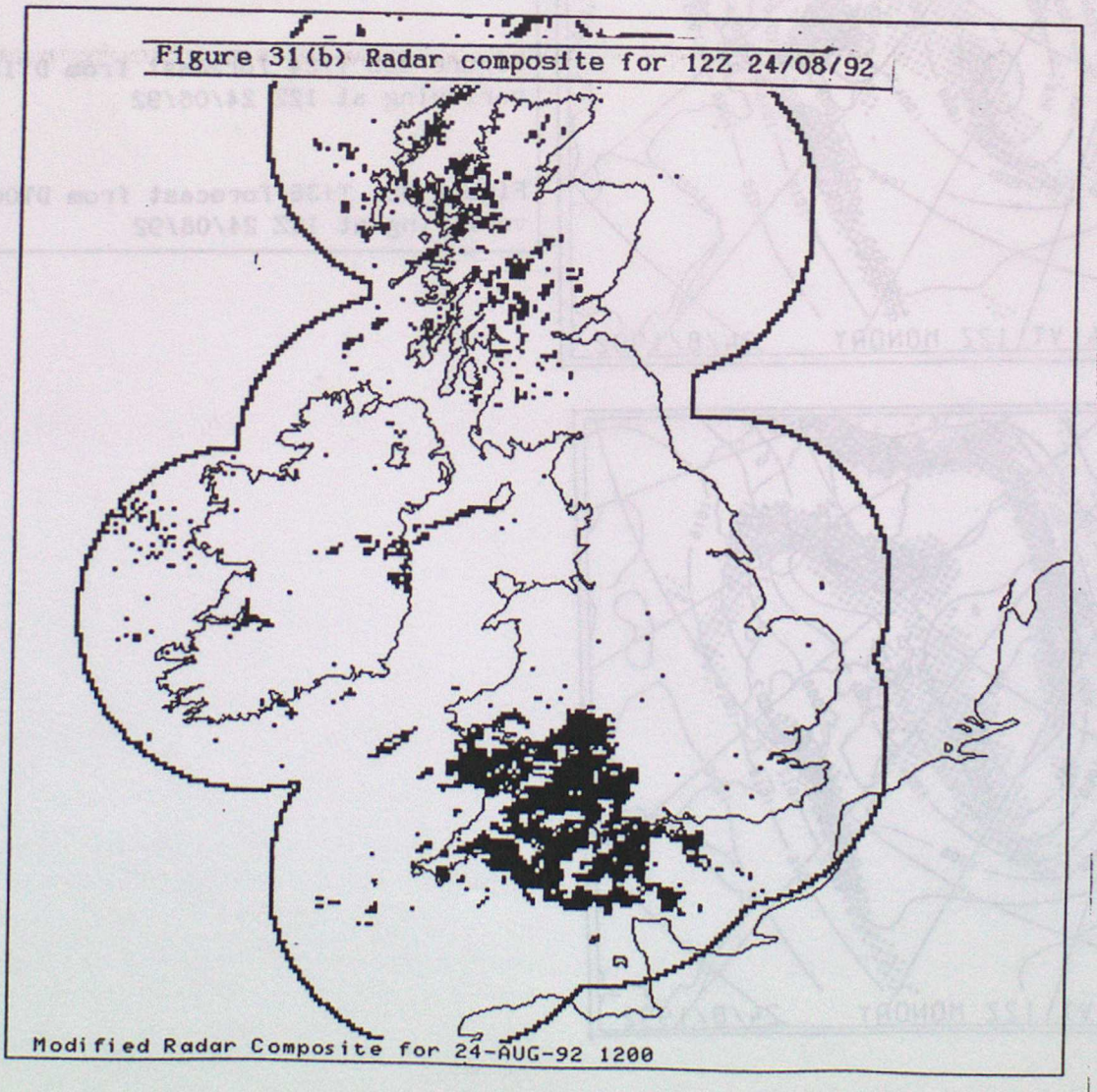
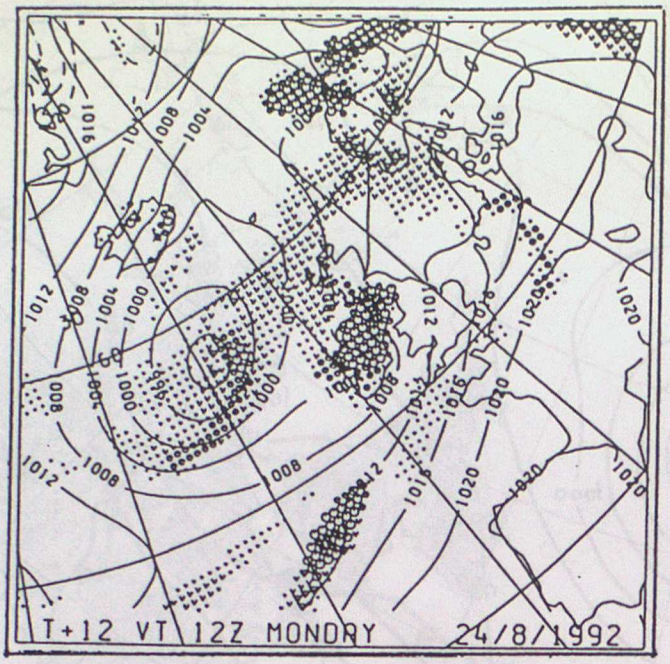
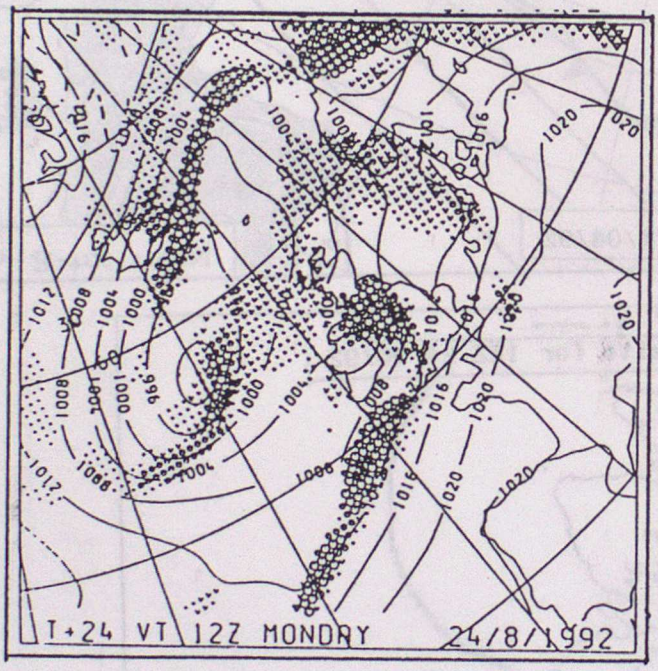


Figure 31(a) Analysis for 12Z 24/08/92

Figure 31(b) Radar composite for 12Z 24/08/92







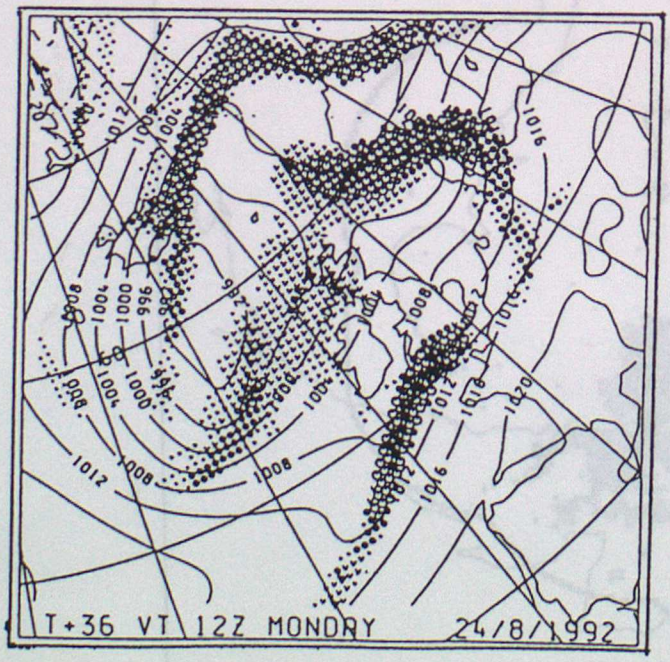


Figure 32a T+12 forecast from DT00Z 24/08/92 verifying at 12Z 24/08/92

Figure 32b T+24 forecast from DT12Z 23/08/92 verifying at 12Z 24/08/92

Figure 32c T+36 forecast from DT00Z 23/08/92 verifying at 12Z 24/08/92

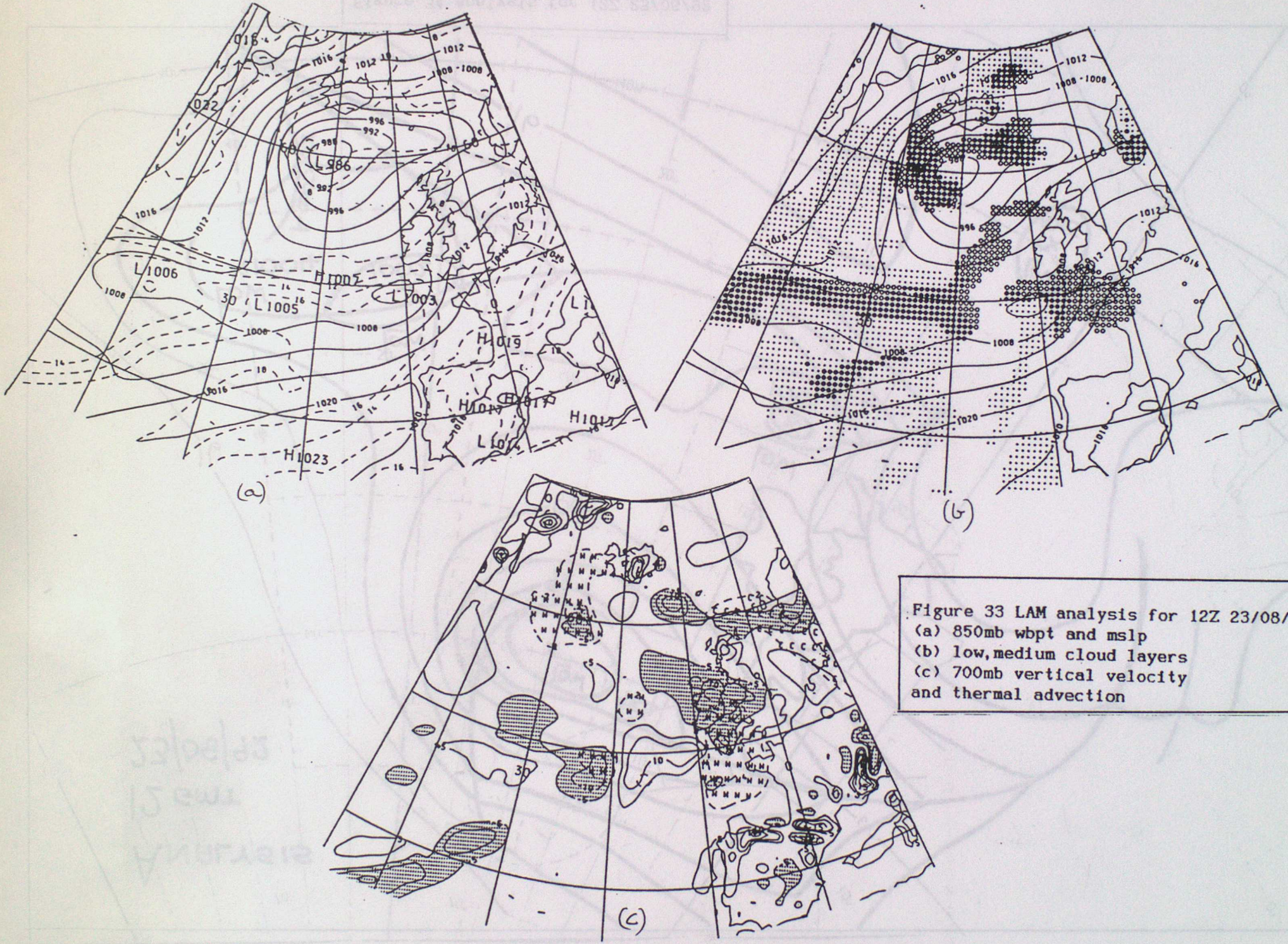


Figure 33 LAM analysis for 12Z 23/08/92
(a) 850mb wbpt and mslp
(b) low, medium cloud layers
(c) 700mb vertical velocity
and thermal advection

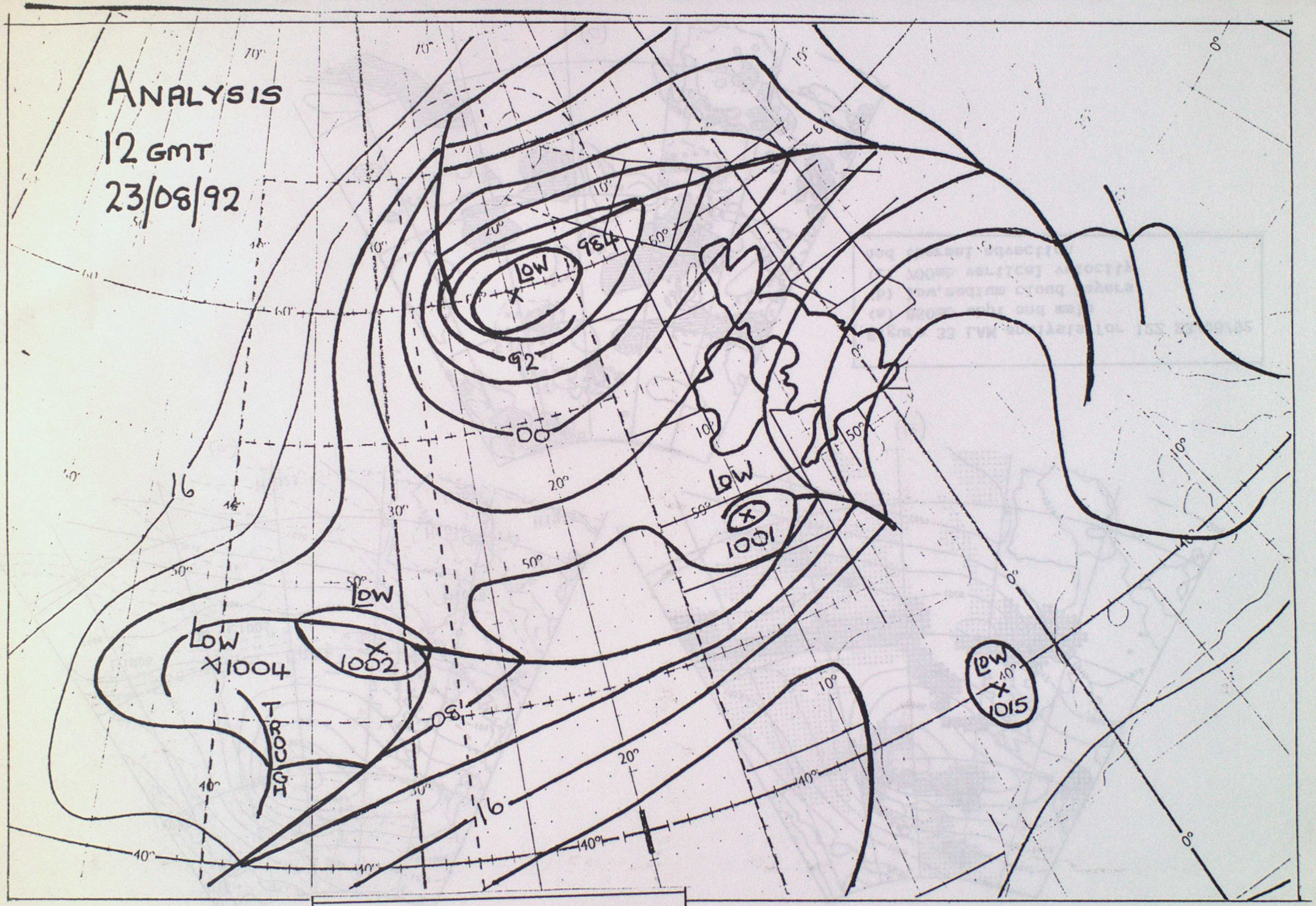
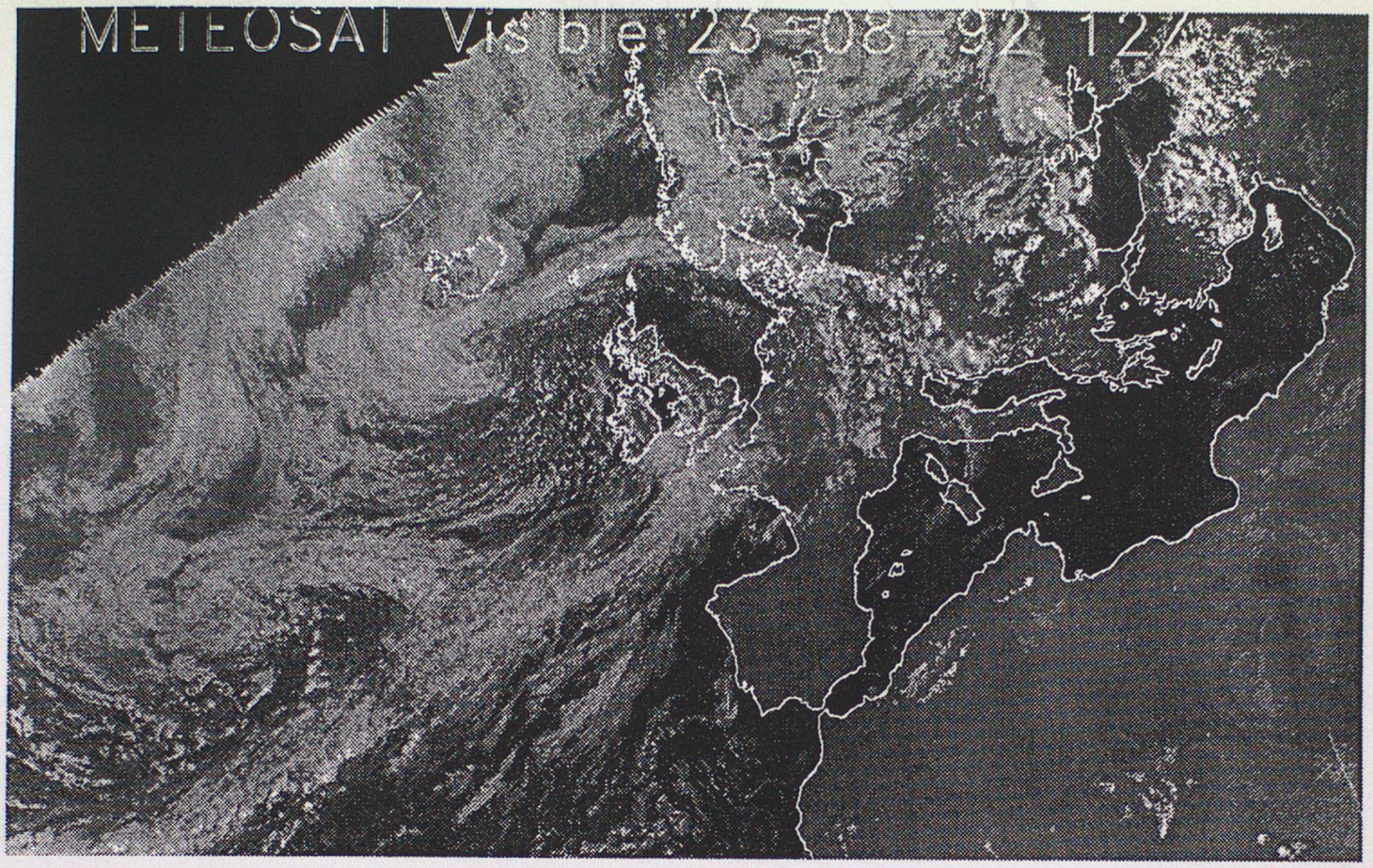


Figure 34 Analysis for 12Z 23/08/92

Figure 35a Meteosat visible satellite image for 12Z 23/08/92
Figure 35b Meteosat infra red satellite image for 12Z 23/08/92



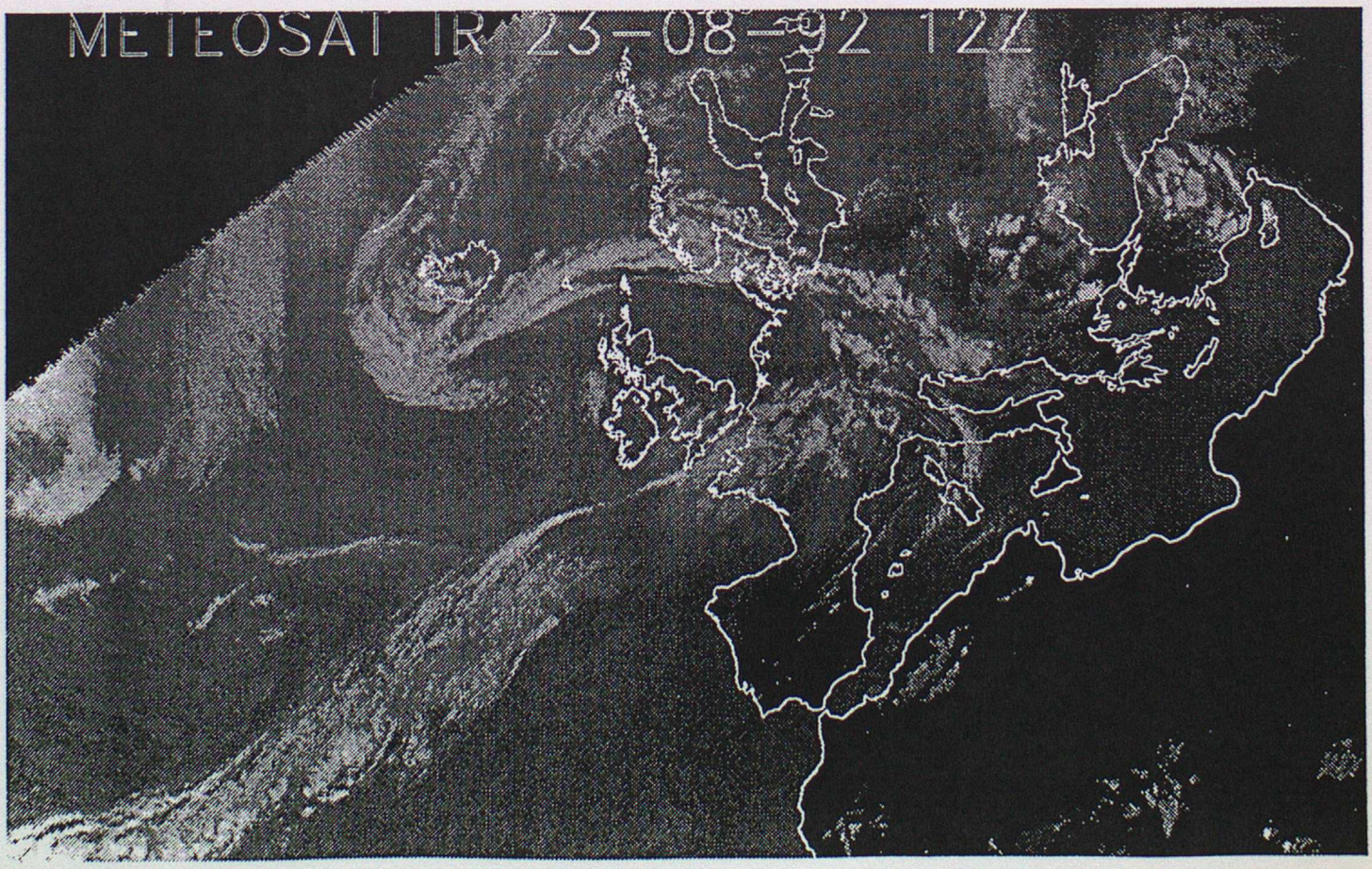


Figure 36a

Wet bulb potential temperature and winds for 850mb valid at 00Z 22/7/93 : forecast T+12

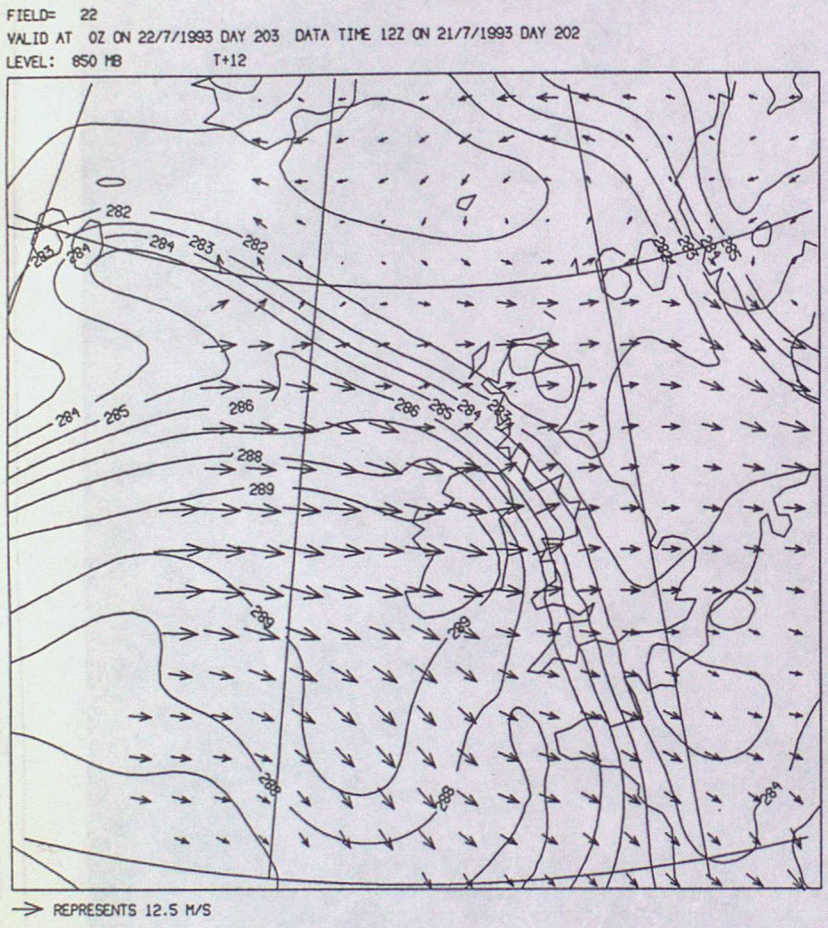


Figure 36b

Wet bulb potential temperature and winds for 850mb valid at 00Z 22/7/93 : analysis T+0

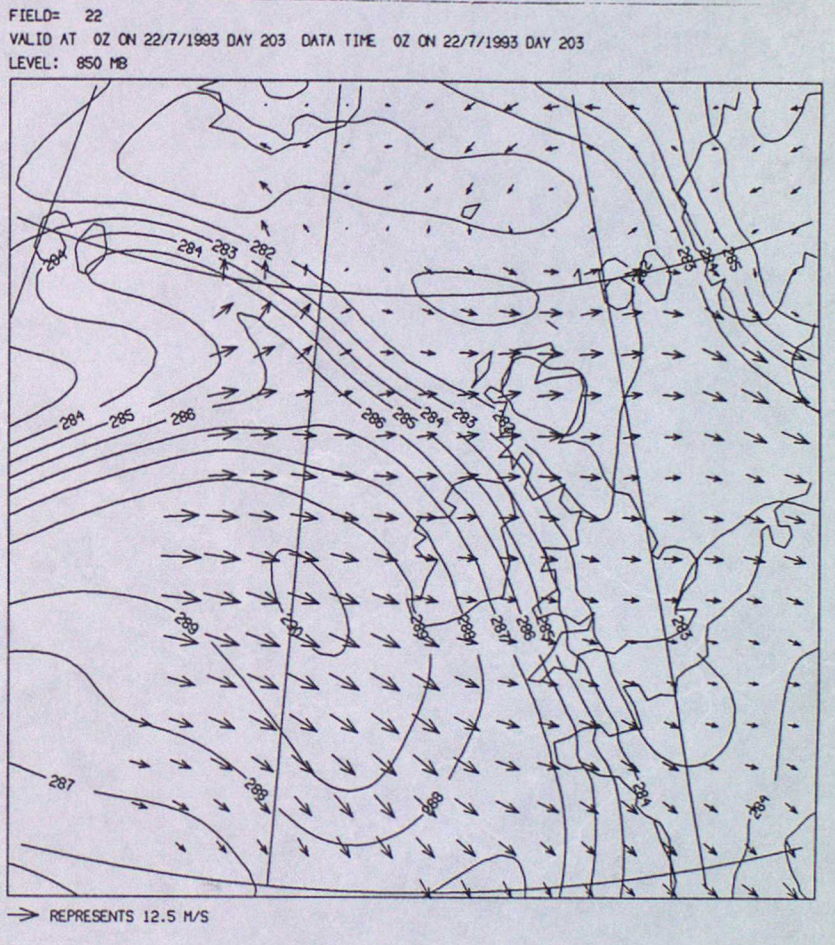


Figure 37a

winds for 850mb valid at 00Z 22/7/93 : forecast T+12

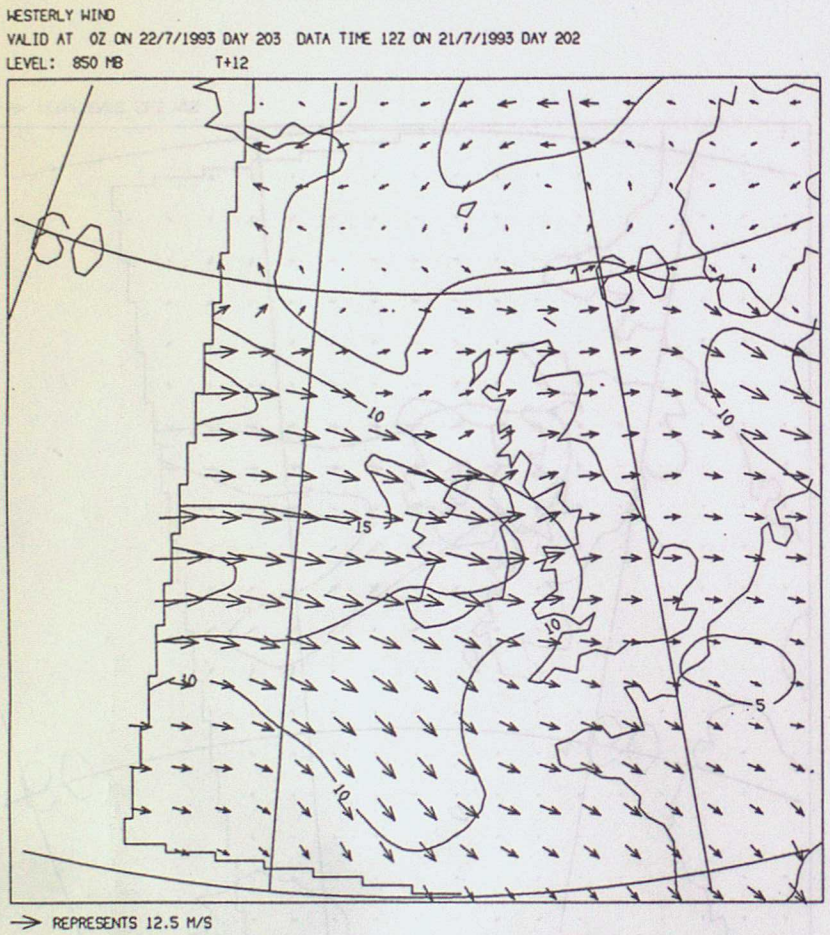


Figure 37b

winds for 850mb valid at 00Z 22/7/93 : analysis T+0

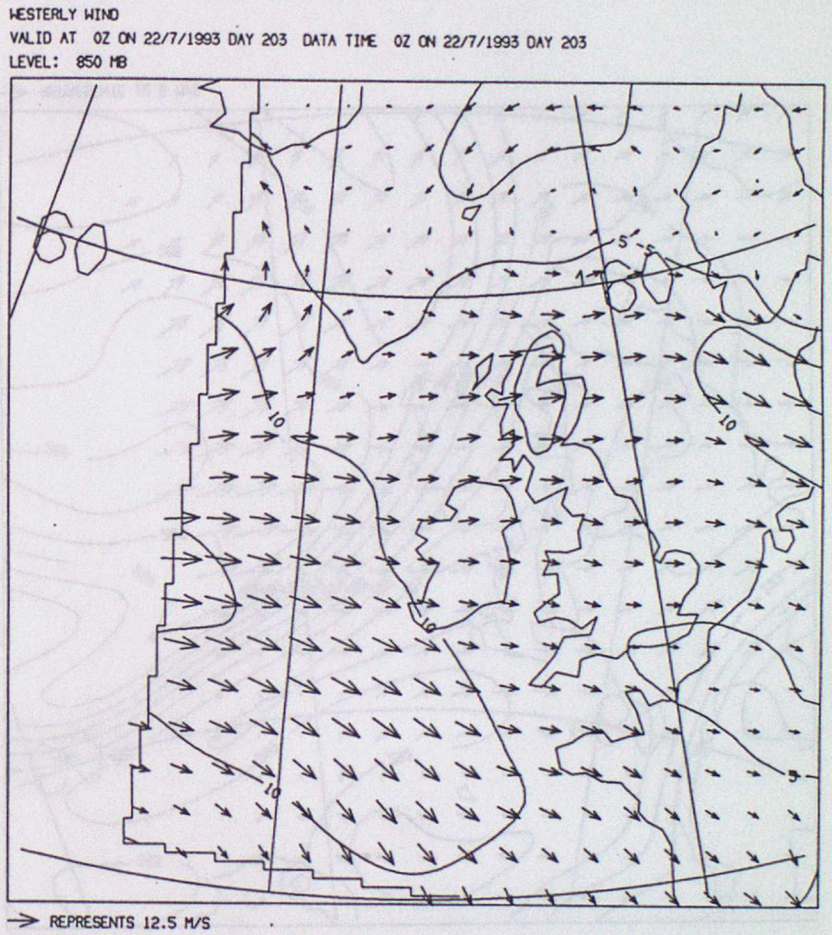


Figure 37c

wind error for 850mb valid at 00Z 22/7/93 : T+12 - verifying analysis T+0

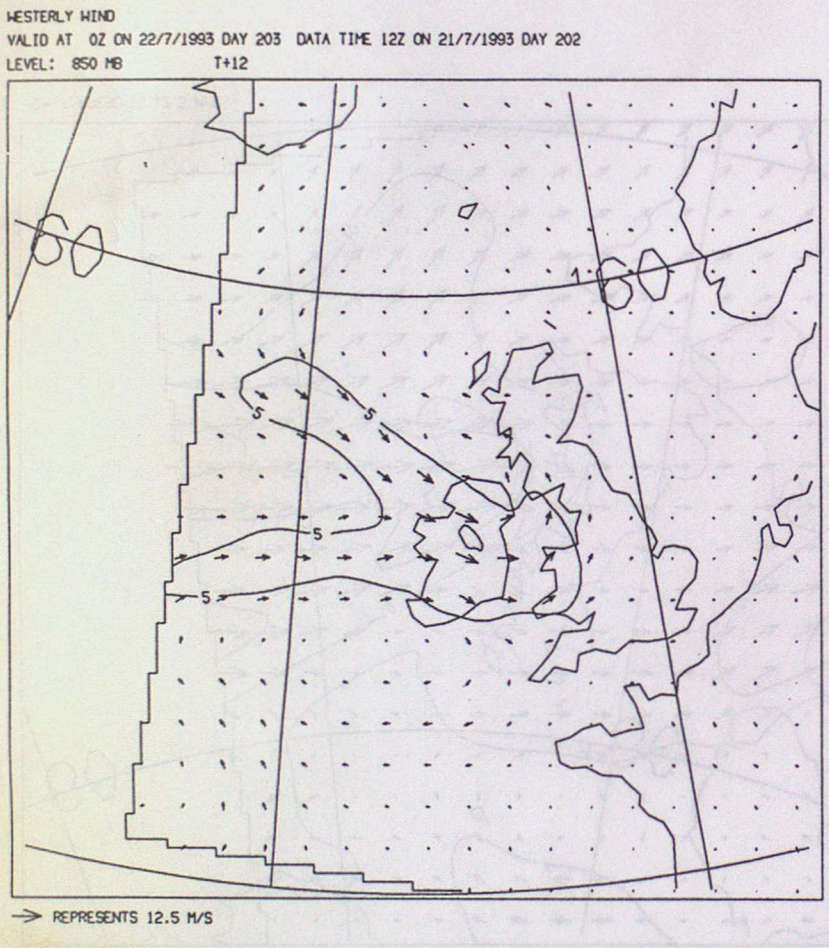
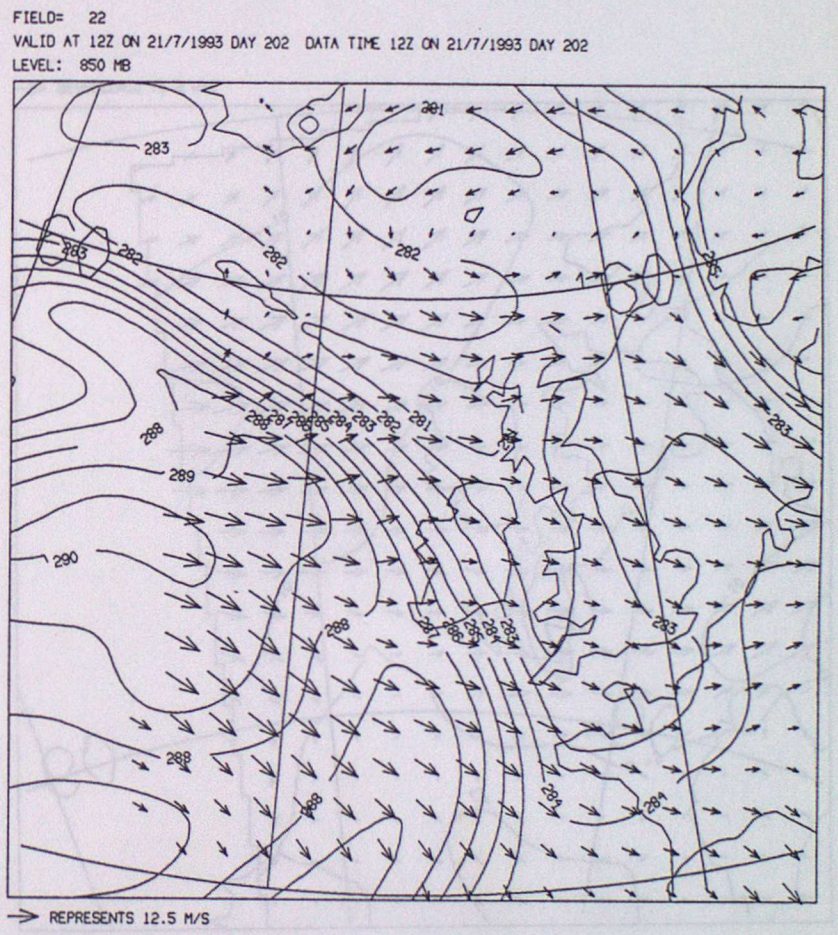


Figure 38

Wet bulb potential temperature and winds for 850mb valid at 12Z 21/7/93 : analysis T+0